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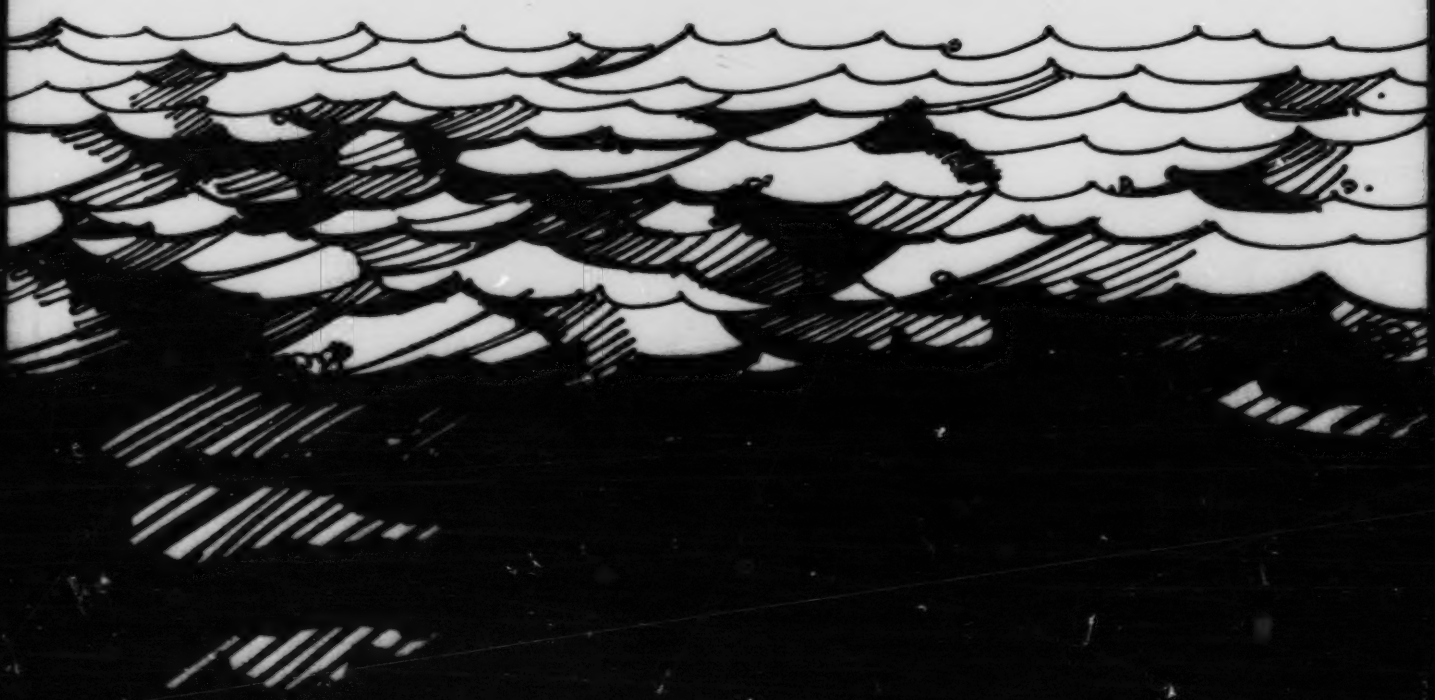
LAKE WABAMUN LITERATURE REVIEW



Lake Wabamun Watershed

LAKE WABAMUN

LITERATURE REVIEW

prepared for

the Lake Wabamun Watershed

Advisory Committee

MARCH 19, 1983

by: Helen Habgood
TECHNICAL ADVISOR

EXECUTIVE SUMMARY

Lake Wabamun is one of Alberta's most heavily used recreational lakes due to its size, proximity to Edmonton and relatively good water quality.

TransAlta Utilities Corp. Ltd. operates two electrical generating plants near the lake, fueled by coal from local surface mines. The Wabamun plant uses lake water in a once-through cooling system, discharging the cooling water at 10° to 15°C above ambient lake temperatures into a shallow bay. The newer Sundance plant originally used the same type of cooling system, but in late 1975 switched to a cooling pond independent of the lake.

Within the last 20 years complaints by cottagers and other lake users of increasing growths of submerged macrophytes have resulted in numerous studies of the lake, mainly regarding the effects of the thermal discharge on submerged macrophytes and other biota.

The heated water indirectly stimulates aquatic macrophyte growth in the discharge area by maintaining an ice-free area which allows winter light penetration and gives plants an earlier start in the spring. The thermal effluent was responsible for a macrophyte species change to dominance by Elodea canadensis. Elodea had not been recorded in the lake prior to 1968; by the early 1970's it was a major nuisance. The thermal discharge created environmental conditions whereby Elodea, which would normally be at the northern limit of its range in Lake Wabamun, was able to outcompete native species by continuing growth throughout the winter in the ice-free areas. However, in the late 1970's most Elodea populations declined dramatically for unknown reasons. One disputed hypothesis is that the plant itself depleted iron in the

sediments to levels that it cannot survive. One major Elodea population remains in the power plant discharge area, and other native macrophyte species continue to be a nuisance throughout the lake.

The Energy Resources Conservation Board required TransAlta to investigate the effect of the thermal discharge on weed growth and the feasibility, cost and effectiveness of various alternative cooling facilitites. TransAlta presently conducts an annual program of cutting and removing weeds in the discharge area which is locally effective in alleviating the nuisance. Consultants' reports suggest that an expanded weed harvesting program would be cheaper and have more predictable results than alternative cooling facilities. Alternative cooling facilities such as cooling towers or spray nodules are not guaranteed to reduce the weed problem, and the associated construction activities might actually worsen the situation. Herbiciding may be effective but to date has been done only experimentally on a small scale; effects of large scale application are unknown. In 1981 the ERCB ruled that alternative cooling facilities were unwarranted at the Wabamun plant and ordered TransAlta to expand the weed harvesting program.

In general, effects of the thermal effluent on vascular plants and other biota are to stimulate production and, in some cases, to alter species composition. Organisms living within the thermal plume area are subject to wide daily temperature fluctuations and higher than ambient temperatures to which some species have a better tolerance than others.

Algal growth continues throughout the winter in the ice-free discharge area, whereas growth is restricted under ice. The discharge does not change species composition of planktonic algae except within the discharge canal itself where blue-green abundance is greater and the number of diatom species is reduced. Species composition of epiphytic

algae (algae attached to Scirpus stems) is altered in the heated area. Within the discharge area the summer phytoplankton standing crop is reduced due to shading from the abundant macrophytes.

Rotifers, which dominate the zooplankton from early spring to mid-July, produce eggs at an increased rate in the heated area; water temperatures greater than 22.4°C may be detrimental to them.

Within the thermal effluent zone the zoobenthos is characteristic of a higher degree of eutrophication than elsewhere in the lake. Species diversity is lower within the discharge canal.

Weed cutting reduces the numbers of those animals associated with the vegetation, although other species increase following cutting. Herbicide is detrimental to zooplankton.

The lake supports a number of fish species, of which lake whitefish is the most important commercially and recreationally. The population is normally characterized by fluctuations, which were perhaps emphasized by over-fishing. Present management strategy emphasizes sport over commercial fishing. The Sundance thermal effluent, before it was eliminated from the lake, was thought to threaten important whitefish spawning area. The effluent caused increased egg mortality, accelerated egg development and too-early hatching. The construction of the Sundance cooling pond eliminated some pike spawning area but did not harm the population. Weed cutting, if done too early in the season, is detrimental to pike fry which cling to vegetation for about one week after hatching.

Water quality in Lake Wabamun is quite good compared with other lakes in the area. Unlike many central Alberta lakes, blue-green algal blooms rarely occur in Wabamun. Its trophic state is mildly eutrophic. It is well-oxygenated and winter anoxia is usually not a problem. The

thermal effluent does not alter the water chemistry. Because of its shallowness and orientation to the wind, the lake is well mixed and permanent summer thermal stratification does not occur.

Quantitative water and nutrient budgets have not yet been established. The lake has no major inflow or outflow streams and is under an evaporative regime. The lake level fluctuates but enhanced evaporation from the thermal discharge has not caused an overall decline. Groundwater is an important recharge source, with the coal units supplying most of the recharge water. Overland runoff of precipitation is the major nutrient contributor, with other sources being direct precipitation, mine drainage and cottages. The contribution of sewage leakage from cottage septic systems is unknown but probably quite small. Bottom sediments are very thick, loose and stirred up, and probably represent a very large nutrient store. They contain significant amounts of biologically available phosphorus and may release phosphorus to the water.

At present, the major on-going research at Lake Wabamun is a provincial government nutrient study which focuses on defining nutrient loading sources and determining whether nutrient control would be feasible and effective in maintaining present water quality.

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I. INTRODUCTION

A. PURPOSE AND SCOPE OF REVIEW

Lake Wabamun is one of Alberta's larger and more important recreational lakes. Within the last 20 years it has received a great deal of scientific and political attention due to conflicts between industrial and recreational interests. The public has become concerned about perceived declining water quality in the lake; increasing weed growth is the main complaint.

The review summarizes the available published scientific literature and as much unpublished literature as possible. Most of the work has been done within the last 15 years but some records go back to the 1920's. The review also includes background information on recreational, residential and industrial uses.

B. LOCATION AND GENERAL FEATURES

Located approximately 64 km west of Edmonton and just south of Highway #16, Lake Wabamun's proximity to Edmonton, size and relatively good water quality make it a very popular recreation resource.

Figure 1 shows the lake and its environs. The main geographical features are the village of Wabamun, a number of summer villages and subdivisions on the lake shores, railroad tracks paralleling the north shore, coal mines north and south of the lake, Wabamun Lake Provincial Park at Moonlight Bay and the Paul Band Indian Reserve at the east end of the lake. The surrounding countryside is rolling aspen parkland forest and agricultural land.

TransAlta Utilities, Ltd. (formerly Calgary Power, Ltd.) operates two coal-fired electric generating plants at the east end of the lake.

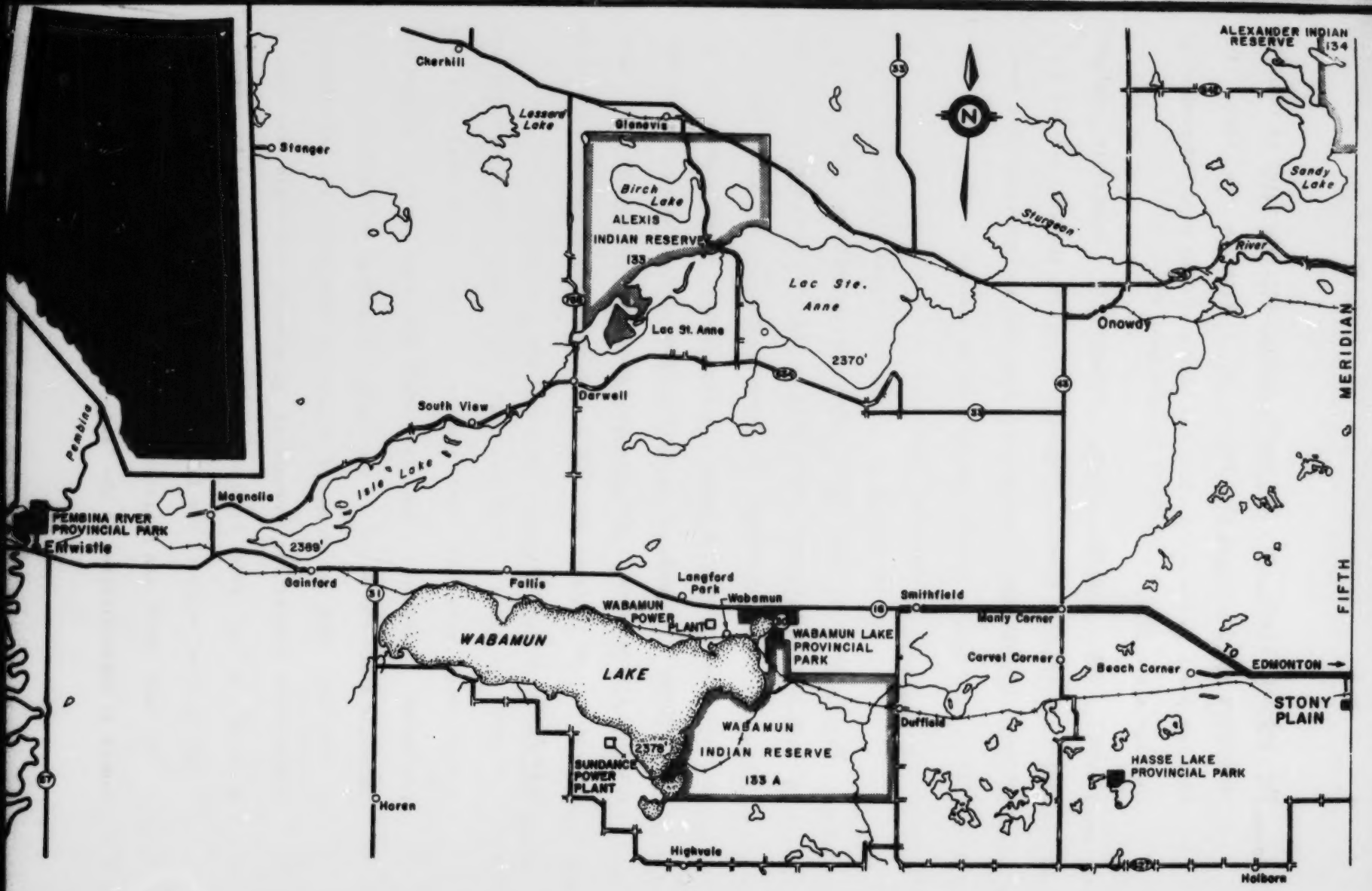


FIGURE 1. LAKE WABAMUN : LOCATION AND SURROUNDING AREA

The Wabamun plant, on the north shore, uses lake water to cool the condensers and discharges the heated water back to the lake. The Sundance plant on the south shore has used a cooling pond independent of the lake since 1975.

Like many prairie lakes, Wabamun is relatively shallow, productive,and with abundant aquatic macrophytes growing naturally in response to nutrient-rich substrate, warm temperatures, and long summer days.

C. THE WEED PROBLEM

Within the last 20 years submerged macrophytes have become a nuisance to recreationists, especially in the shallower east end of the lake. The main objections to weed growths are that weeds tangle on outboard motor propellors, snag fishing lines, inhibit swimming and water sking and wash up on beaches where they decompose. Weeds have probably always grown in the lake and were a nuisance to the first cottagers. As early as the 1930's a mechanical weed cutter was used at Seba Beach (Beak 1980).

Since the 1960's cottagers and other lake users have expressed concern about excessive weed growths to both Trans Alta and the provincial government. Many lake users feel that the weed problem has increased since the advent of the thermal discharge to the lake.

In late 1978 a group of concerned citizens, the Lake Wabamun Preservation Association, requested government officials to find a solution to the weed problem. Their primary aim was to promote a "comprehensive" study of the lake and its watershed.

In late 1979 the Minister of Environment initiated a study on the causes of eutrophication in the lake, and in 1980 he established the

Lake Wabamun Watershed Advisory Committee to make recommendations regarding the maintenance or improvement of water quality.

D. OVERVIEW OF LAKE WABAMUN STUDIES

The first survey of aquatic macrophytes was done for Trans Alta by Dobson and Stanley (1961) who identified extensive weed growths in the east end of the lake. They also found that macrophytes were a much greater nuisance at Lake Wabamun than at Pigeon Lake or Lac Ste Anne.

TransAlta has monitored weed growth by aerial photographs taken annually since 1961 (Allen and Gorham 1973).

In 1968 University of Alberta scientists undertook an interdisciplinary project to study the effects of heated water on the ecosystem of Lake Wabamun. They produced an interim report which determined that the heated effluent caused definite alternations of the aquatic ecosystem and probably accelerated the eutrophication rate, altered life cycles of organisms, and generally increased the rate of productivity and standing crop (Gallup 1971). Numerous papers originating from the interdisciplinary project have been published.

Topics include:

the effect of thermal effluent on phytoplankton (Noton 1974),

attached algae (Hickman 1974, Hickman and Klarer 1974, 1975),

diatoms (Hickman 1976),

rotifers (Horkan 1971),

zoobenthos (Folsom 1976, Gallup, Hickman and Rasmussen 1975, Rasmussen 1979),

whitefish (Ash 1974, 1975)

Elodea and other submerged macrophytes (Allen 1973, Haag 1979, Haag and Gorham 1977, 1979)

physical and chemical effects of thermal effluent (Gallup and Hickman 1975);

ionic composition of lake and groundwater (Nursall, Nuttall and Fritz 1972, Fritz and Krouse 1972, 1973, Schwartz and Gallup 1978);

Aquatic snail populations and parasites (Sankurathri and Holmes 1976 a and b).

A final report in the form of an annotated bibliography was issued by Nursall and Gorham (1981).

Other investigations have dealt with macrophyte control by dredging (Reynoldson 1977), and sediment chemistry (Allan and Williams 1978). Paleolimnology is currently being studied by Schweger et al. (1981) and Hickman (unpubl.).

In 1972 the Alberta Department of the Environment, in response to the public concern expressed at Energy Resources Conservation Board (ERCB) hearings in January 1972, commissioned Reid, Crowther and Partners Ltd. to carry out a study to estimate what deterioration had occurred and to recommend remedial measures. The 1973 Reid, Crowther "Lake Wabamun Study" reviewed existing literature and compiled findings of earlier studies; they recommended a 263 ha cooling pond at the

Sundance plant, cooling towers at the Wabamun plant, and piping make-up water from the North Saskatchewan River at a rate of 2067 L/s to replace evaporative losses and regulate lake levels within a "desirable" range.

In 1973 the ERCB ordered TransAlta to provide studies to satisfy the Board that the waste heat discharged does not contribute to weed growth and spread in Lake Wabamun (ERCB 1973). In 1975 the Board also required the company to submit by 1980 a general environmental impact statement and revised cost estimates for possible alternative cooling facilities at the Wabamun plant. (ERCB 1976, IEC 1979).

TransAlta contracted Beak Consultants Ltd. to conduct the aquatic weed studies; research was done from 1974 to 1979 (Beak 1975-1979) and the final report was issued in April 1980. This report concluded that some changes in the aquatic plants and other biota in the lake were related to the waste heat. The overabundance of Elodea canadensis, a macrophyte which had not been observed in Lake Wabamun prior to 1968, was an acute problem from 1970 to 1974, but has since declined. Beak also stated that Elodea is no longer a nuisance and it is unlikely to return to nuisance proportions. They speculated that the "crash" of Elodea after 1974 was due to depletion of available iron in the sediments, caused by the plant itself. Beak recommended mechanical and herbicidal control of weeds rather than alternate cooling facilities (Beak 1980) at the Wabamun facility.

Montreal Engineering Company, Ltd. (MEC) outlined feasible cooling alternatives and estimated costs for the Wabamun plant (MEC 1979). They concluded that the most economical choice would be extension of the discharge canal to deeper water, the next most economical alternative would be discharge water tempering.

International Environmental Consultants, Ltd. (IEC) prepared an environmental impact statement for TransAlta (IEC 1979) which covered various cooling facilities and their potential biological and social impacts. Spray and cooling tower systems were found to have the greatest negative impacts, and they would not reduce the weed problem. The most attractive alternative, in terms of impacts and cost, was expanded weed harvesting.

In 1980 Alberta Environment undertook a three-year study to address whole-lake nutrient enrichment. Goals of the study are to quantify major nutrients entering the lake, assess present trophic condition and determine feasibility of nutrient control. An interim report (Mitchell et al. 1981) was recently released; the final report is expected in 1983.

II. BACKGROUND

A. PHYSICAL FEATURES

Lake Wabamun is a shallow, productive, hardwater lake, somewhat elliptical in shape with its long axis lying east-west. It may be a remnant of a long, narrow post-glacial lake which included other lakes in the area (Nursall and Gallup 1971).

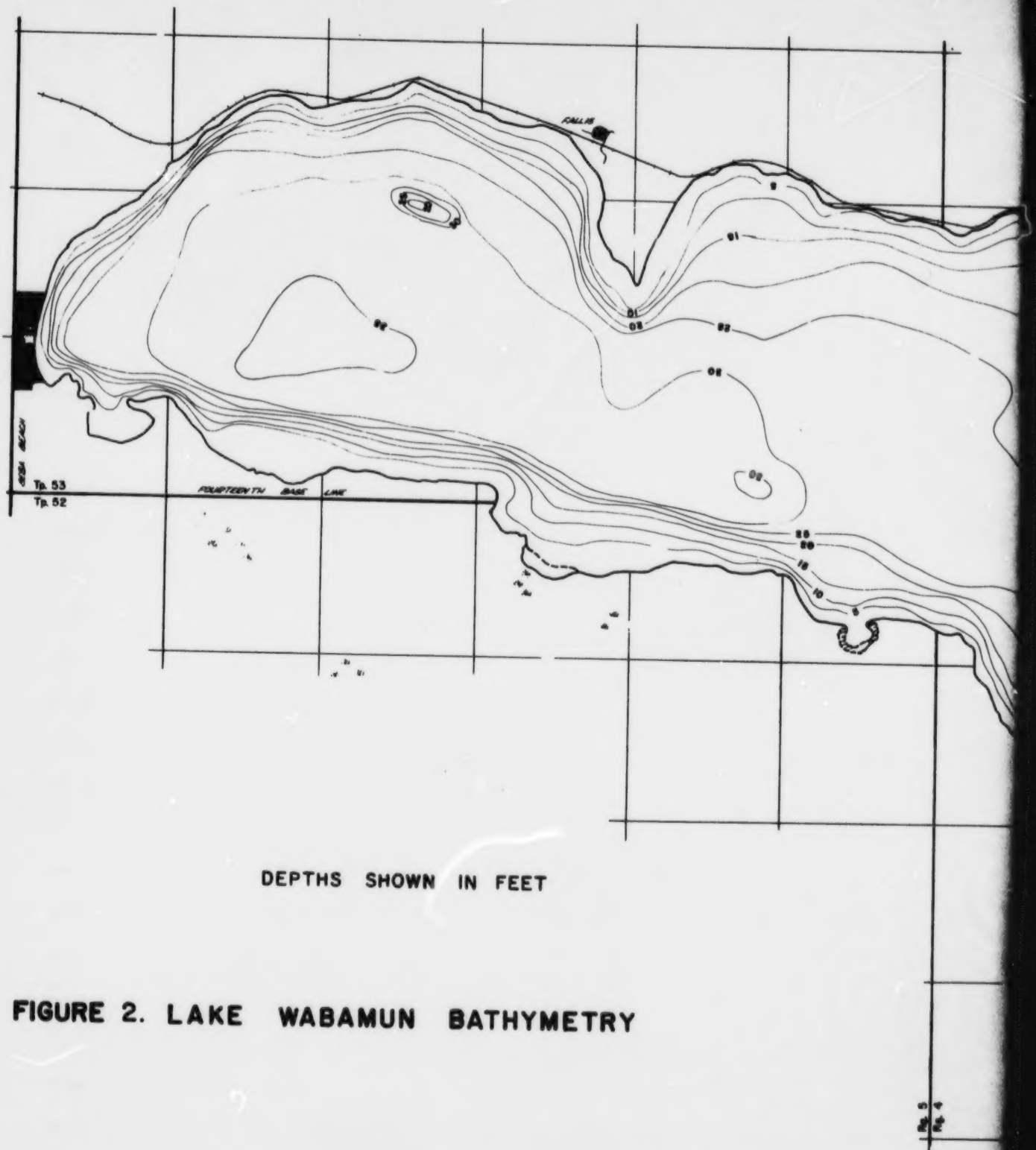
Table 1 summarizes morphometric data and Figure 2 shows the bathymetry. Lake Wabamun is 19.2 km long and an average of 4.3 km wide. The maximum depth is 11.6 m, the west end being approximately 1.75 times deeper than the east end. Twenty-two percent of the west end and 56% of the east end are less than 4 m deep, which is the approximate depth limit for rooted aquatic plants (Reid, Crowther 1973). Approximately 40% of the shoreline is in a natural state and 30% is occupied by cottage development (IEC 1979).

Surface drainage within the watershed is to the east, but inflow to and outflow from the lake are relatively minor. There are two outlets which join to form Wabamun Creek, a small stream which flows from the east end of the lake into the North Saskatchewan River. The more northerly of the two outlets, excavated anonymously sometime after 1912 and known as the "illegal outlet" has a small control structure on it; the southern outlet is the natural one. Various attempts at regulation of water level fluctuations have been made by alterations to the outlets, by dam building or channel excavation (Beak 1980).

Table 1. Morphometric summary of Lake Wabamun. (From IEC 1979)

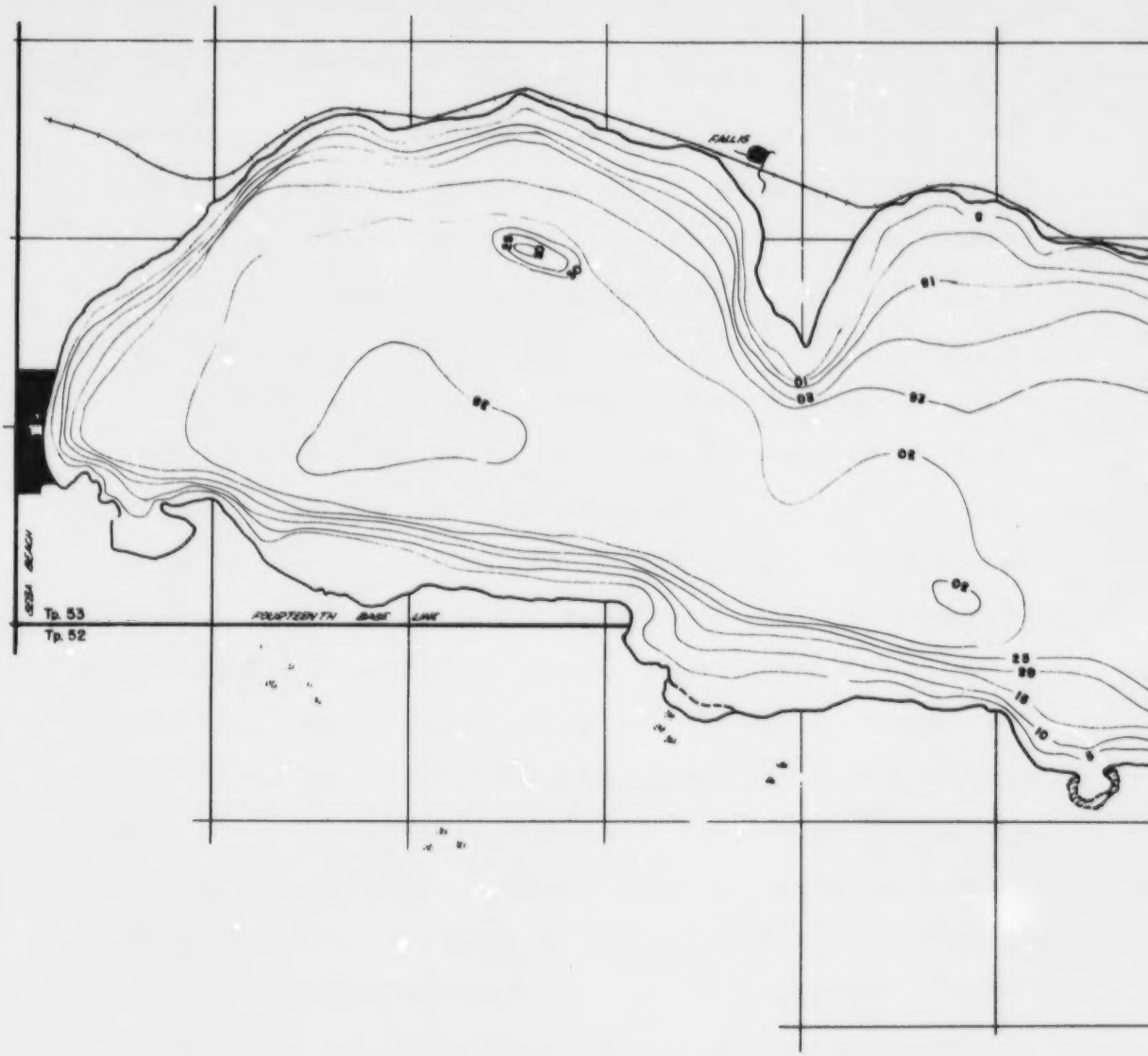
Mean Elevation	724.2 m above sea level (722.7 m CNR datum)
Maximum Level on Record	725.15 m above sea level (May 1927)
Minimum Level on Record	723.81 m above sea level (November 1961)
Total Drainage Area[1]	340.5 km^2
Lake Surface Area[1]	77.7 km^2
Lake Volume	503×10^6 m^3
Maximum Length	19.2 km
Maximum Breadth	6.6 km
Mean Breadth	4.3 km
Maximum Depth[1]	11.0 m
Mean Depth for Lake[1]	6.4 m
Deep Water East End	8.1 m
Deep Water West End	10.7 m
Area of lake less than 3.96 m (13 ft.) deep[2]	
East end	56%
West end	22%
Total Shoreline Length	57.3 km
Shoreline on Wabamun Indian Reserve	ca. 8.5 km
Shoreline Cottage Development	ca. 17 km
Other Development of Shoreline (includes wharves, power plants, CNR)	ca. 8.5 km
Shoreline in fairly natural state	ca. 23 km

1. From Alberta Environment 1980 Hydrographic Survey
2. From Reid, Crowther 1973



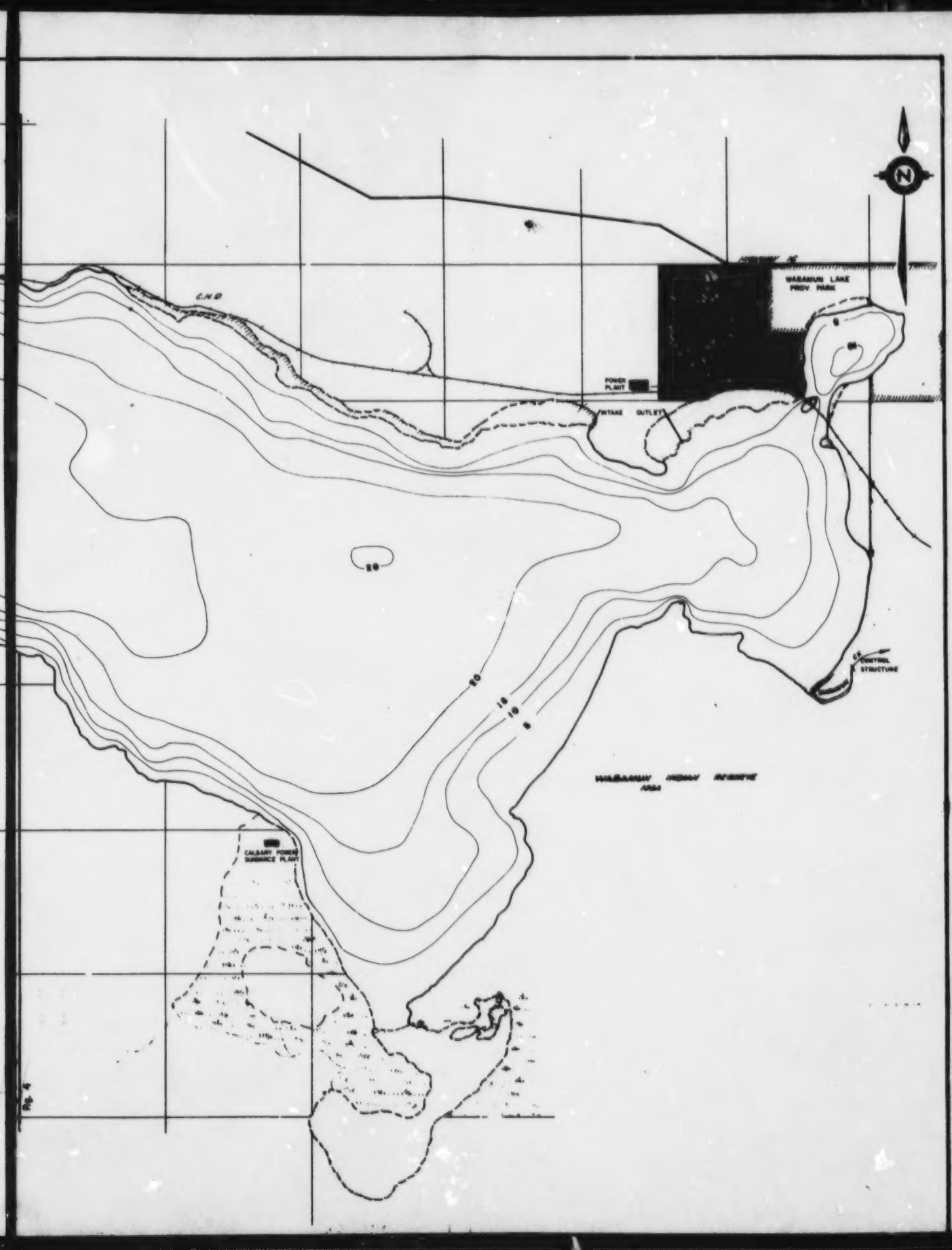
DEPTHS SHOWN IN FEET

FIGURE 2. LAKE WABAMUN BATHYMETRY



DEPTHS SHOWN IN FEET

FIGURE 2. LAKE WABAMUN BATHYMETRY


C.N.R.
WABAMUN LAKE
PROV. PARK
POWER
PLANT
INTAKE
OUTLET
CONTROL
STRUCTURE
CALGARY POWER
SUBBASE PLANT

B. POST-GLACIAL HISTORY

Central Alberta topography has been shaped by continental glaciation; the region is composed mainly of poorly drained glacial drift covering the underlying bedrock. The uplands were formed by ground and end moraines while the lowlands were once glacial lake bottoms (Bird 1961).

At the end of the continental glaciation about 10 000 years ago, the ice sheet retreated by stagnation, impounding melt waters which formed large, short-lived lakes (Bayrock and Hughes 1962).

Following the ice retreat was a warming and drying trend from approximately 10 000 to 4000 BP (before present) (Ritchie in press), which was most pronounced in central Alberta from 8700 to 6300 BP (Schweger et al. 1981). Vegetation zones shifted to the north, soil water tables and lake levels were substantially lower (Ritchie in press) and many shallow lakes dried up (Schweger et al. 1981). During this period many central Alberta lakes show increased calcium and carbonate concentrations in their sediments, indicating increased productivity due to algae, and submerged and emergent macrophytes (Schweger et al. 1981).

Between 6000 and 4000 BP conditions were moderated by a cooler and moister climate; lake levels rose and vegetation zones shifted southward. Lake productivity declined between 3000 and 2000 BP and it was during this time that present day vegetation patterns became established (Ritchie in press, Schweger et al. 1981).

In a study of Lac St Anne and Hastings Lake, Forbes (1980) found that productivity was never nutrient limited, and that macrophytes probably contributed to a greater proportion of total production during the earlier, less productive stages of the lakes' history.

Even at their inception, following the retreat of the glacier, these lakes were probably never as clear and unproductive as Canadian shield lakes.

C. CLIMATE

Three climatological monitoring stations near Lake Wabamun, with long and complete records, are located at Sion (about 40 km to the northeast of Lake Wabamun), Edmonton International Airport (about 55 km to the east) and Edson (about 90 km to the west). Sion and Edmonton are better indices for Lake Wabamun than Edson, which is influenced by its proximity to the mountains. Less complete records are also available from Stony Plain and Highvale (IEC 1979).

The climate of the area may be characterized as having long, bright, moderately warm summer days, and short, bright, cold, dry winter days (IEC 1979). The average annual precipitation is between 48.3 and 50.8 cm. Monthly precipitation is greater during the summer with 68% to 76% of the precipitation occuring as rain. Snow covers the area from mid-October through mid-April. Annual potential evapotranspiration is 63.5 to 71.1 cm and is greater than the precipitation from May through October (Ozoray 1972).

Mean daily temperatures for January and July are -16°C and 16°C, respectively. Mean annual daily temperature is about 1.5°C (IEC 1979).

Prevailing winds are from the northeast to southeast.

D. TERRESTRIAL VEGETATION

The surrounding area is a mixture of agricultural land and natural forest. The natural vegetation is in the mixed wood section of the Boreal Forest region (Rowe 1959), is characterized by a mixture of trembling aspen (Populus tremuloides),black cottonwood (P. balsamifera), white birch (Betula papyrifera), white spruce (Picea glauca) and balsam fir (Abies lasiocarpa). Aspen and cottonwood have become dominant due to fire; spruce and fir dominate older stands (IEC 1979).

Low-lying areas near the lake support sedge (Carex spp.) and willow (Salix spp.) communities. Other important species in these areas are sloughgrass (Bechmannia syzigachne), tamarack (Larix laricina), wolf willow (Elaeagnus commutata), aspen and cottonwood (IEC 1979).

E. GEOLOGY

Bedrock geology of the Wabamun area was first mapped by Rutherford in 1928 and more recently by Green (1972). Bedrock topography was mapped by Carlson (1971). Surficial geology has been mapped by Wyatt et al. (1930) in their soil survey, by Collins and Swan (1955) and by Andriashek et al. (1979). Coal reserves in the area have been described by Pearson (1959).

Present day drainage patterns generally follow preglacial drainage channels but in some areas they have been modified by glaciation. Preglacial bedrock valleys in the Wabamun and Edmonton map areas have been mapped by Carlson (1966, 1971)(Fig.3), and Andriashek et al. (1979)(Fig.4). Such a valley exists northwest of Lake Wabamun, running from Entwhistle beneath Lake Isle and Lac Ste Anne to the Sturgeon River. Carlson suggested that Lake Wabamun also lies within a

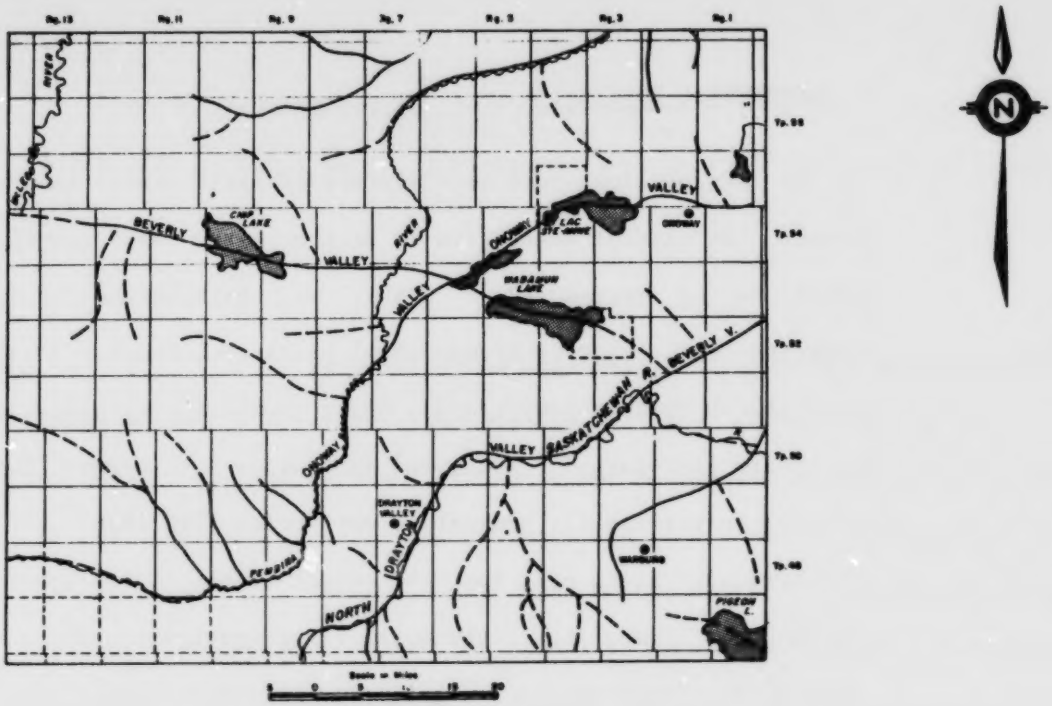


FIGURE 3. THALWEGS FOR BEDROCK VALLEYS INTERPRETED TO BE GLACIAL (from Carlson 1971)

FIGURE 4. THALWEGS AND DRIFT THICKNESS
(from Andriashek et al 1979)

preglacial bedrock channel running west to east, and the lake was formed by glacial debris damming the channel. However, subsequent mapping by Andriashek et al. (1979) and the Groundwater Branch of Alberta Environment (1980) yielded no evidence of this channel; it appears that Lake Wabamun lies in a depression formed and/or enlarged by glacial ice thrusting.

North, west, and south of the lake the uppermost bedrock is the Paskapoo Formation consisting of non-marine Tertiary deposits of sandstone and sandy shale. It is the uppermost formation in most of west-central Alberta east of the foothills; its eastern boundary runs through the east end of Lake Wabamun and then north between Lake Wabamun and Lac Ste Anne (Green 1972). The basal portion of the Paskapoo formation, the Scollard member, contains coal (Pearson 1959) which is being mined at the Highvale and Whitewood mines (Figure 5).

The Horseshoe Canyon Formation of the Edmonton Group, of upper Cretaceous age, is thinly overlain by the Paskapoo Formation at Lake Wabamun; east of the lake where it is not overlain by the Paskapoo it is the uppermost formation (Green 1972). The Edmonton Group consists of non-marine bentonitic shale and shaly sandstone (Pearson 1959).

In the immediate area of Lake Wabamun glacial drift is less than 15 m thick; it is thicker northeast and southeast of the lake. Surficial deposits are thinnest along the north and southwest shores of the lake where bedrock outcrops occur. As the basin of Lake Wabamun was formed by Pleistocene glaciation, material was removed from the basin and deposited southwest of the lake forming the low distorted bedrock hills presently seen there. Thus in this area the strata above the coal layers may consist of remnants of Edmonton Group rocks from the north, as well as Paskapoo Formation rocks (Baldwin 1981).

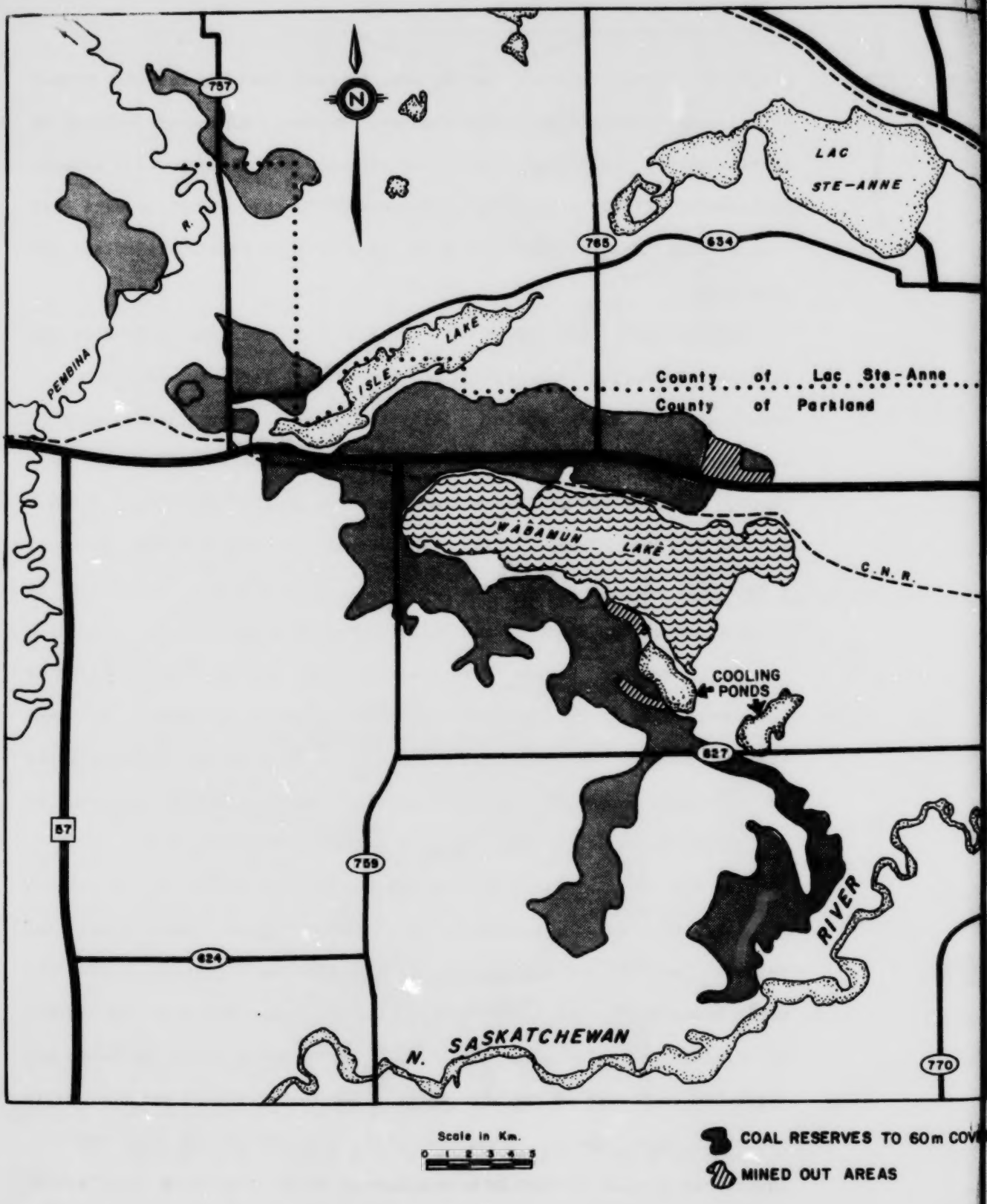


FIGURE 5. COAL RESERVES IN THE LAKE WABAMUN AREA
(from WHOA 1980)

The surficial deposits around Lake Wabamun consist mainly of ground moraine composed of till, lacustrine and beach sands, and gravels (Andriashek 1979). The glacial till north of the lake originates mainly from the Horseshoe Canyon Formation. To the south and west of the lake is of Paskapoo Formation origin. Beach sands and gravels occur in a narrow strip along the north and west shores of Lake Wabamun. To the north, south, and east of the lake surficial deposits are of glacial or glaciolacustrine origin. Thin or discontinuous till and glaciolacustrine deposits cover distorted Paskapoo Formation bedrock to the southwest (Andriashek et al. 1979).

F. SOILS

Soils of the Lake Wabamun area were first mapped by Wyatt et al. (1930) and then in more detail by Lindsay et al. (1968). In general, the soils around Lake Wabamun are of the Gray Wooded type, characterized by low nitrogen, mineral and organic content due to leaching. Productivity is poor to fairly good. (Edmonton District Planning Committee 1956).

The Cooking Lake series, a moderally well drained Orthic Gray Wooded developed from till of the Horseshoe Canyon Formation is the major soil type north and west of the lake. West and south west of the lake the Modesto series, a well-drained Orthic Gray Wooded Soil derived from the Paskapoo formation is prominent. Also to the south are the Kavanaugh and Kawood series which are Solonetzic soils developed from the Horseshoe Canyon Formation. Organic soils of poorly drained sedge and sphagnum peat, the Eaglesham and Kenzie series, are found in a large area to the southeast around Goosequill Bay. The Codesa series is a minor component developed from shallow outwash or alluvial deposits that

overlie till (Lindsay et al. 1968). Periodically there are deposits of sand which give rise to good beaches, such as at Seba Beach, making the Codesa series recreationally important (Anderson 1967).

Most of the soils surrounding the lake have moderately severe to severe limitations for agriculture, thereby restricting the range of crops which can be grown. These soils may be difficult to till, absorb water poorly or have a restricted rooting zone depth (Canada Land Inventory, Soil Capability for Agriculture 1972).

G. HYDROGEOLOGY

Hydrogeology for the Lake Wabamun area has been mapped by Topp (1969) and Ozoray (1972). According to Ozoray, the lake is within a zone where groundwater potential ranges from 20-100 L/min. The best aquifer is west of the lake where yields are up to 400 L/min (Topp 1969). Elsewhere in the Wabamun drainage basin yields range from 4 to 60 L/min.

Groundwater is hard with a high calcium bicarbonate content. Total dissolved solids are generally low, less then 500 ppm (Ozoray 1972).

The Edmonton Group is generally a poor aquifer; its high clay content gives it low permeability. The Paskapoo Formation is a somewhat better aquifer although it is quite variable. The sandstone components are superior to the shales. The best aquifers are associated with the bedrock channels (Topp 1969).

Regional groundwater movement is from the vicinity of Lake Isle and the associated preglacial channel, through the coal and sandstone aquifers of the Paskapoo formation to Lake Wabamun, then from the east end of the lake toward the North Saskatchewan River (Fritz and Krouse 1973, Schwartz and Gallup 1978). The coal units north of the lake are

the most important regional aquifer discharging into the lake (Schwartz and Gallup 1978). Along the south shore of the lake groundwater above the coal layers flows toward the lake, while below the coal it flows toward the southwest (Alberta Environment, Groundwater Branch 1980).

Lake levels have been recorded intermittently between the years 1916 and 1960 and continuously thereafter. As can be seen from Figure 6 the level fluctuates widely, both within a year, and from year to year. Highest water occurs in May or June due to spring freshets. The highest and lowest recorded water levels were, respectively, 723.7 m in May 1927 and 722.3 m in April 1961 (CNR datum).

No marked decline in lake level is evident since the installation of the power plants, as was feared might result from enhanced evaporation due to the thermal effluent.

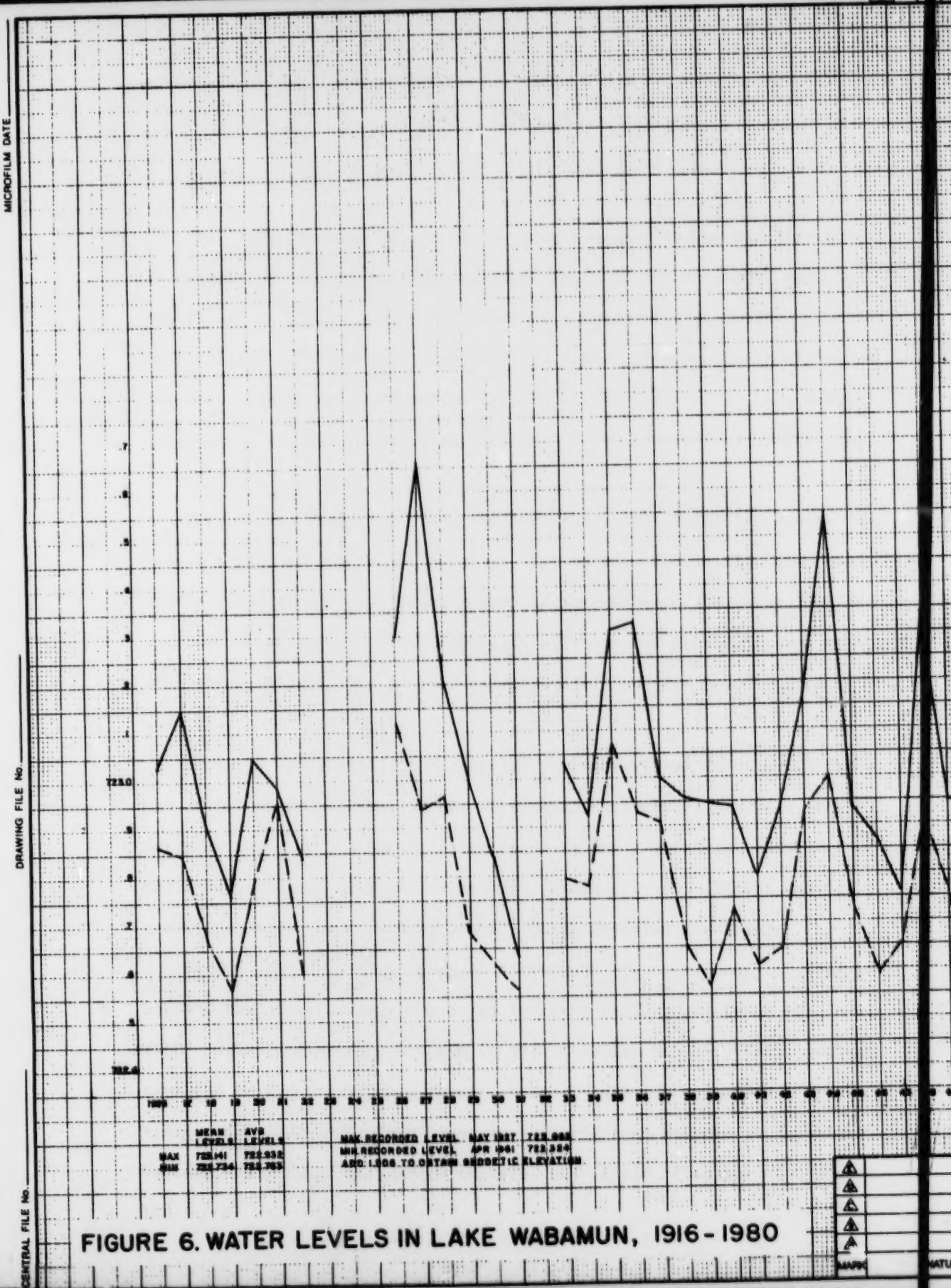
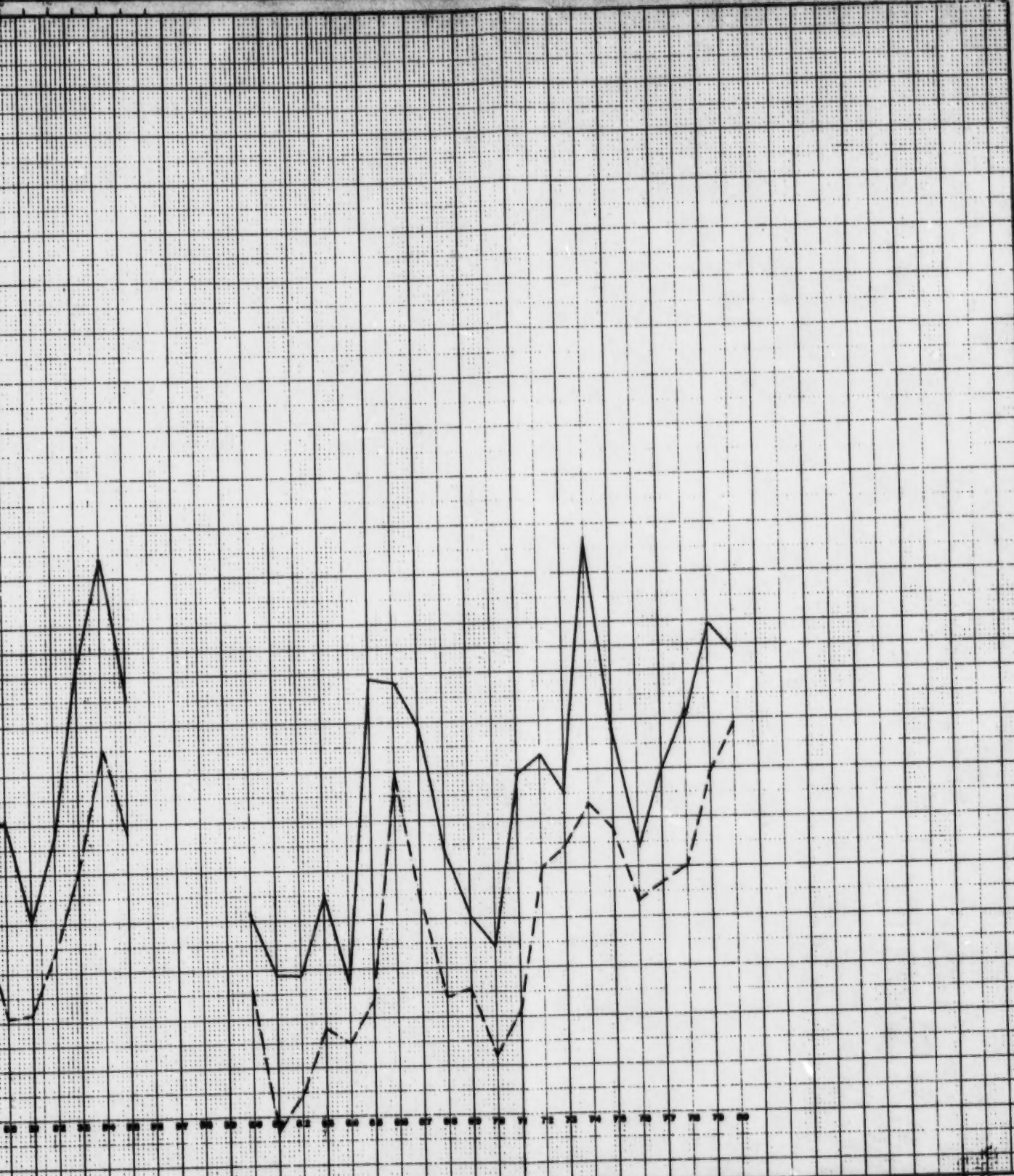


FIGURE 6. WATER LEVELS IN LAKE WABAMUN, 1916 - 1980



OF REVISION	DATE	ENG.	DWN.

Alberta ENVIRONMENT — DESIGN AND CONSTRUCTION DIVISION

SUBMITTED	DESIGNED .....
DATE	CHECKED .....
APPROVED	DRAWN B. HEBBERT .....
DATE	CHECKED ..... / .....

LAKE WABAMUN LAKE LEVELS 1916 - 1980

—— MAXIMUM LEVELS
— — MINIMUM LEVELS

SCALE	SHEET 1 OF 1
DATE 1980/09/05	DRAWING No.

III. HUMAN USE

A. HISTORICAL BACKGROUND

The Lake Wabamun region was originally inhabited by the Sarcee and Blackfoot Indians but by 1725 they were replaced by the Woods Cree and their allies the Stonies. The Stonies, surrendering to advancing white civilization in the 1880's, were divided between reserves in Montana and Alberta. The Paul Band on the reserve at the east end of Lake Wabamun is a member of the Alberta branch of the Stony Indians (Parks Division, no date).

The first Europeans came to the area in the late 1790's with the Hudson's Bay and Northwest Companies, but it was not until the early 1900's that permanent residents came to Lake Wabamun. Missionaries and settlers established a small community northeast of Moonlight Bay which was then moved to the present location of Wabamun village between 1909 and 1912.

Westward extension of the railway brought an influx of settlers to the area. In 1905 homesteaders established themselves at Seba Beach. Early settlers grazed their livestock up to the lake's edge resulting in the destruction of much of the natural shore cover. There was also extensive haying on the south shore. (Parks Division, no date).

Before the railway, people travelled by horse and carriage to Wabamun then transferred to a ferry to reach various points on the lake. With rail service to Wabamun in 1910 (Lindsay et. al. 1968) families took the train to spend the summer at their lakeside cottages. Special trains for day and weekend excursions to the lake stopped at Kapasiwin, Wabamun, Fallis and Seba Beach (Makale and Kyllo Planning Associates Ltd.

Before World War 1, Wabamun village prospered as a summer resort and a local commercial centre for farmers. Growth declined with WWI but picked up somewhat in the late 1940's when coal strip mining began; the Wabamun thermal plant and the Building Products plant were developed in the 1950's (IEC 1979). Wabamun Lake Provincal Park was established in 1955 (Parks Division). Small scale coal mining has existed since 1913 and until 1935 all mines were underground (Parks Division). Now the two large strip mines north and south of the lake, which supply the power plants, are the main resource extraction industries in the area.

Recreational use, summer cottage and summer village development have grown at Lake Wabamun with Edmonton's expanding population and improved transportation access to the lake.

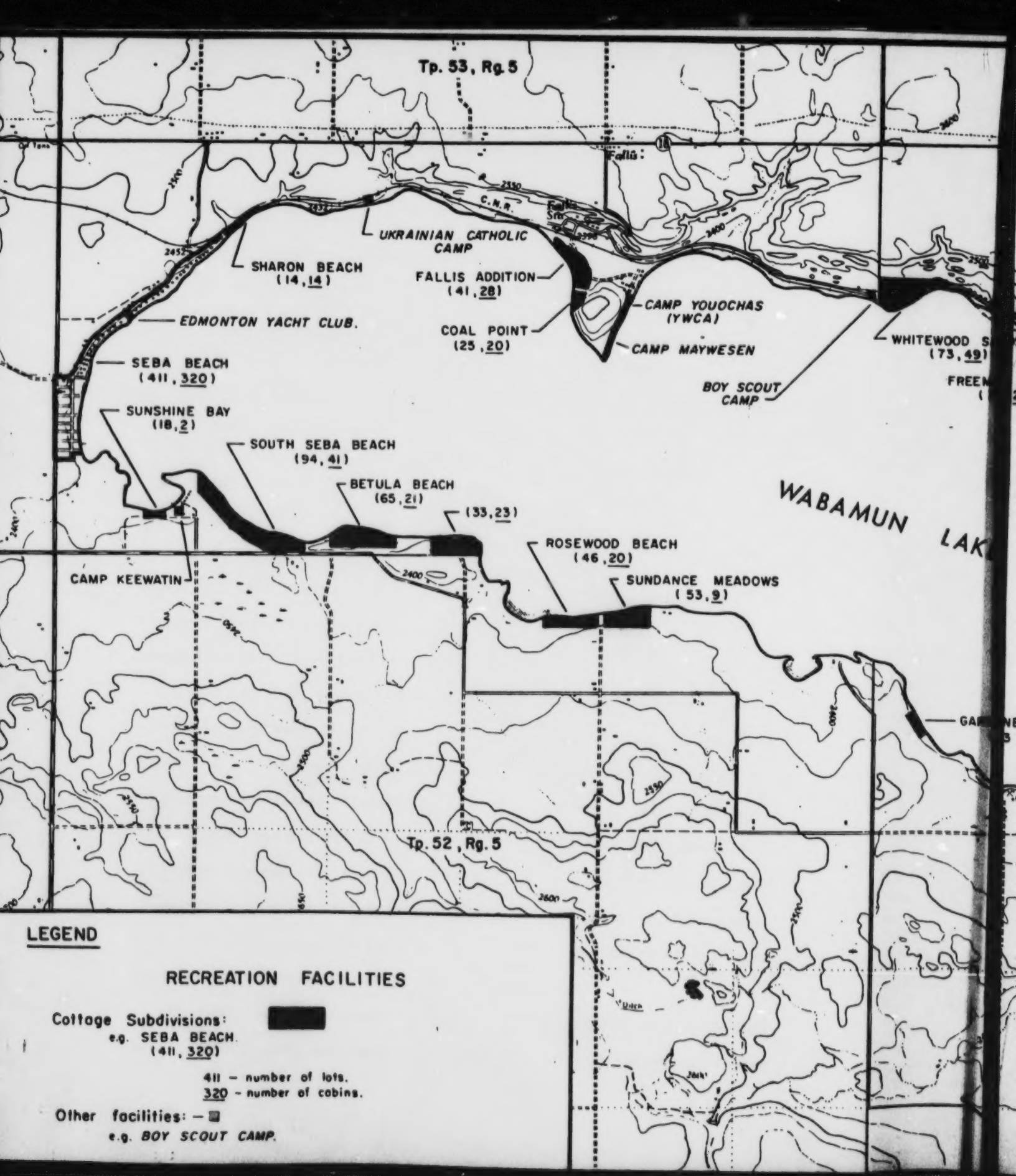
B. RESIDENTIAL AND RECREATIONAL DEVELOPMENT

The village of Wabamun, with a 1980 population of 637, is the only sizable permanent settlement in the vicinity of Lake Wabamun. Its economic base can be attributed to the TransAlta developments; 80% of the labor force is employed in mining, construction or other thermal plant activities associated with the Wabamun and Sundance plants (IEC 1979). The remainder of the labor force is employed by Building Products of Canada Ltd. in the local, commercial, and public service sectors except for a few residents who commute to Edmonton. The commercial sector serves residents, local farmers, summer residents and cottagers in the area, and provincal park patrons. The services available in Wabamun are: grocery store, hardware store, hotel and restaurant, garage, credit union, and laundry. The public services available are: school (grades 1 to 9), post office, arena, public library, police station, and volunteer fire department.

Residential development around the lake consists mainly of private cottages, subdivisions, and summer villages, for which few population data exist. There are five self-governing summer villages around the lake: (1) Point Alison,(2) Lake View, (3) Kapasiwin,(4) Betula Beach and(5) Seba Beach. Unincorporated subdivisions are administered by the County of Parkland. Figure 7 shows the summer villages, subdivision and other recreational facilities around the lake. About 30% of the total shoreline has been subdivided for residential or institutional use (Water Resources Division 1970). The proximity of the CNR line to the north shore precludes further residential or institutional use (Water Resources Division 1970).

Excluding the village of Wabamun, there are 1624 lots around the lake, of which 1301 have been developed. Of these, 130 are permanent residences, the remainder are summer and weekend cottages.

Table 2 summarizes data on residential development, based on information from ratepayer sheets.


Tp. 53, Rg. 5
UKRAINIAN CATHOLIC CAMP
SHARON BEACH (14, 14)
FALLIS ADDITION (41, 28)
EDMONTON YACHT CLUB.
CAMP YOUOCHAS (YWCA)
COAL POINT (25, 20)
CAMP MAYWESEN
WHITEWOOD S (73, 49)
SEBA BEACH (411, 320)
BOY SCOUT CAMP
SUNSHINE BAY (18, 2)
SOUTH SEBA BEACH (94, 41)
BETULA BEACH (65, 21)
(33, 23)
WABAMUN LAK
ROSEWOOD BEACH (46, 20)
CAMP KEEWATIN
SUNDANCE MEADOWS (53, 9)
Tp. 52, Rg. 5
LEGEND
RECREATION FACILITIES
Cottage Subdivisions:
e.g. SEBA BEACH (411, 320)
411 - number of lots.
320 - number of cabins.
Other facilities: —
e.g. BOY SCOUT CAMP.

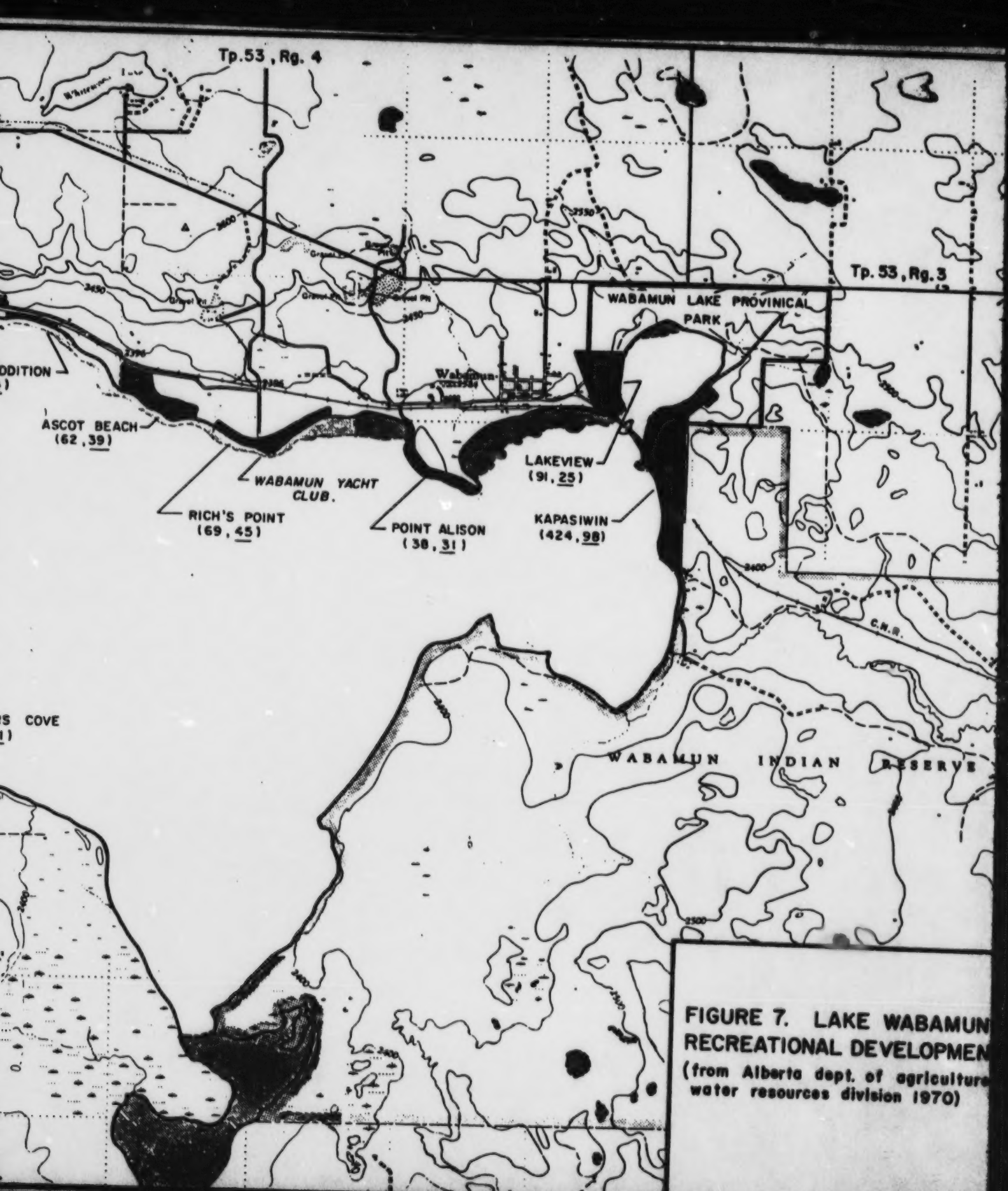


FIGURE 7. LAKE WABAMUN RECREATIONAL DEVELOPMEN

(from Alberta dept. of agriculture water resources division 1970)

Table 2. Residential development at Lake Wabamun, as of 1979 (excluding the Village of Wabamun)

Total No. of lots		1624
Developed:	permanent residences	130
	temporary residences	1171
	total no. of residences	1301

Summer Villages	Total number of lots	No. of temporary residences	No. of permanent residences
Betula Beach	71	1	45
Point Allison	40	3	31
Lakeview	53	5	32
Seba Beach	394	30	350
Kapasiwin	47	1	45

Other recreational facilities include six institutional camps (such as church and boy scouts), two yacht clubs, four community halls, a recreation park, a sportsfield, and a curling rink.

Prior to 1975, sewage effluent from the village of Wabamun received secondary treatment in a lagoon before being discharged into Lake Wabamun. A Trans Alta subdivision in Wabamun had a separate lagoon and discharge to the lake. Concern about lake pollution and an Alberta Environment recommendation to combine the Trans Alta subdivision with the village eventually resulted in the construction of a secondary treatment, one-year retention lagoon about 5 km north of the village, with discharge into a creek within the Lac Ste. Anne watershed (Alberta Environment, Standards and Approvals Division files).

Cottages in the summer villages and subdivisions have individual septic fields, pump out tanks or pit privies. A total-retention sewage

lagoon for holding tank disposal has been constructed for Seba Beach and the surrounding area (Francl and Assoc. 1981).

C. PUBLIC RECREATIONAL FACILITIES

Wabamun Lake Provincial Park is the only public recreation facility of any significance at Lake Wabamun. The park was established in late 1955 and has since expanded to its present size of 280 ha. It has 2282 m of shoreline. A 288-site campground takes up about 50% of the developed area and a day-use picnic area comprises an additional 25%. Facilities provided include shelters, tables, stoves, toilets, showers, sand beach, pier, boat launch, playground, concession and hiking trails (Water Resources Division 1970).

Recreational activities in the park are water-centered and include sailing, power-boating, swimming, water skiing, and fishing. Winter use is much less than summer and includes cross-country skiing, snowmobiling, and ice fishing.

When the park was first created it was necessary to upgrade the beach by removing weeds, dredging, and spreading sand. This increased the Canada Land Inventory Recreational Capability rating to Class 2 (Water Resources Division 1970).

Water weeds became a serious problem in the park in the 1960's with low lake levels and the appearance of Elodea in 1968, which grew so thickly that Moonlight Bay was virtually unnavigable. Chemical control (2, 4-D) was used to control weeds, but was discontinued because of its cumulative effects (Water Resourses Division 1970). In 1971 the park purchased a weed harvester which Trans Alta took over the following year.

Table 3, which summarizes summer use of the park for the last four summer seasons and 1970, demonstrates the popularity of the park. In 1980, between May and October, over 30 000 individual camper nights and over 73 000 day-user days were recorded.

An attractive water and beach resource, proximity to Edmonton, and easy access from a major highway makes this one of the most popular and heavily patronized parks in the province.

The only public facilities at the lake are a pier and boat-launching area at Wabamun village and the same at Seba Beach.

Table 3. Wabamun Lake Provincial Park Attendance Statistics (May through September)a

	1980	1979	1978	1977	1970b
Total no. vehicles	37 626	67 373	58 565	54 266	93 325
Total no. vehicles - camping	8 845	10 888	10 975		6 008
Total no. vehicles - day use	24 524	56 491	37 231		
Total no. individual camper nights	30 973	36 253	36 659	36 816	
Total no. day users days	73 572	169 473	68 001c	97 371	
% of time campground at less than 50% capacity	82	76	82	73	
No. of stalls in campground	288	288	364	364	204

a. Source: 1977-1980 Dept of Recreation and Parks, Parks Division, West Central Region; Annual statistics.

1970 Water Resources Div. and Provincial Parks Div. 1970. Wabamun Lake Study.

b. April through August

c. Traffic counter broken down

D. RECREATIONAL CAPABILITY

The Canadian Land Inventory (CLI) uses the Canadian Land Capability Classification for Outdoor Recreation. The basis of this system is the physical quality of the landscape as an indicator of an area's probable economic potential for recreation (Anderson 1967). The categories range from Class 1, with a high capability, to a low of Class 7.

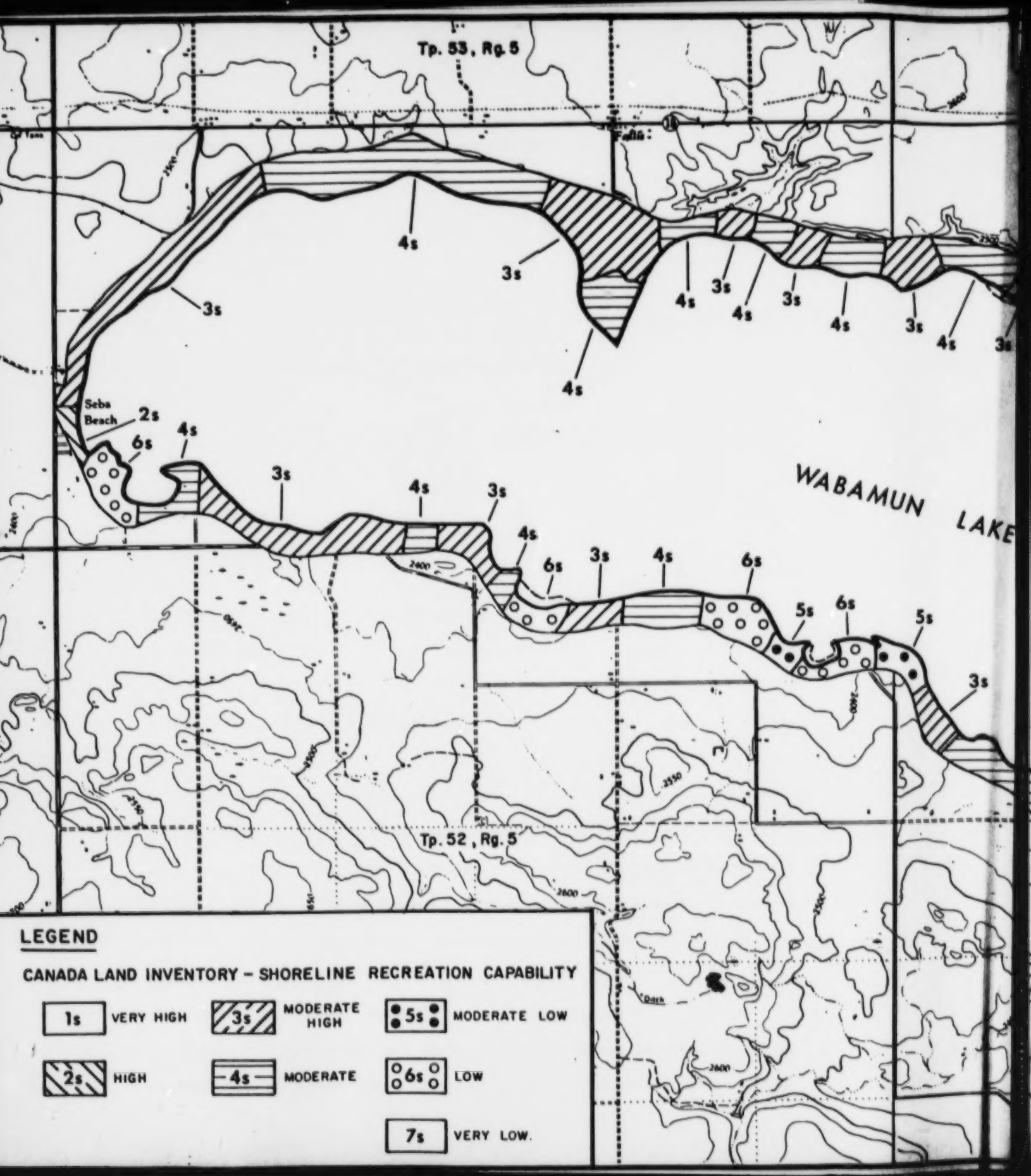
The Canadian Land Inventory has classified the Lake Wabamun shoreline; the results of the CLI classification of the Lake Wabamun shoreline are shown in Figure 8 and are tabulated by class in Table 4.

Table 4. Shoreline recreational capability, Lake Wabamun. (From Water Resources Div. 1970).

CLI Class	No. of units	Total length, m
2 - S	2	1 657.5
3 - S	16	19 682.2
4 - S	17	20 873.3
5 - S	5	9 157.1
6 - S	8	7 692.5

In a recreational capability comparison of Lake Wabamun and Lesser Slave Lake, Anderson (1967) found Wabamun to be generally of mediocre quality, having only two Class 2 beaches (at the provincial park and Seba Beach) and no Class 1 shoreline units. Lesser Slave Lake has a higher recreational capability but is much more isolated. Despite its lack of Class 1 beaches, Wabamun is much more popular and heavily used than Lesser Slave Lake because of its proximity to Edmonton.

As would be expected, the recreational use is concentrated on the higher-rated shoreline areas. All of the Class 2 shoreline and 66.5% of


Tp. 53, Rg. 5
Seba Beach
WABAMUN LAKE
Tp. 52, Rg. 5
LEGEND
CANADA LAND INVENTORY – SHORELINE RECREATION CAPABILITY
1s VERY HIGH
2s HIGH
3s MODERATE HIGH
4s MODERATE
5s MODERATE LOW
6s LOW
7s VERY LOW.

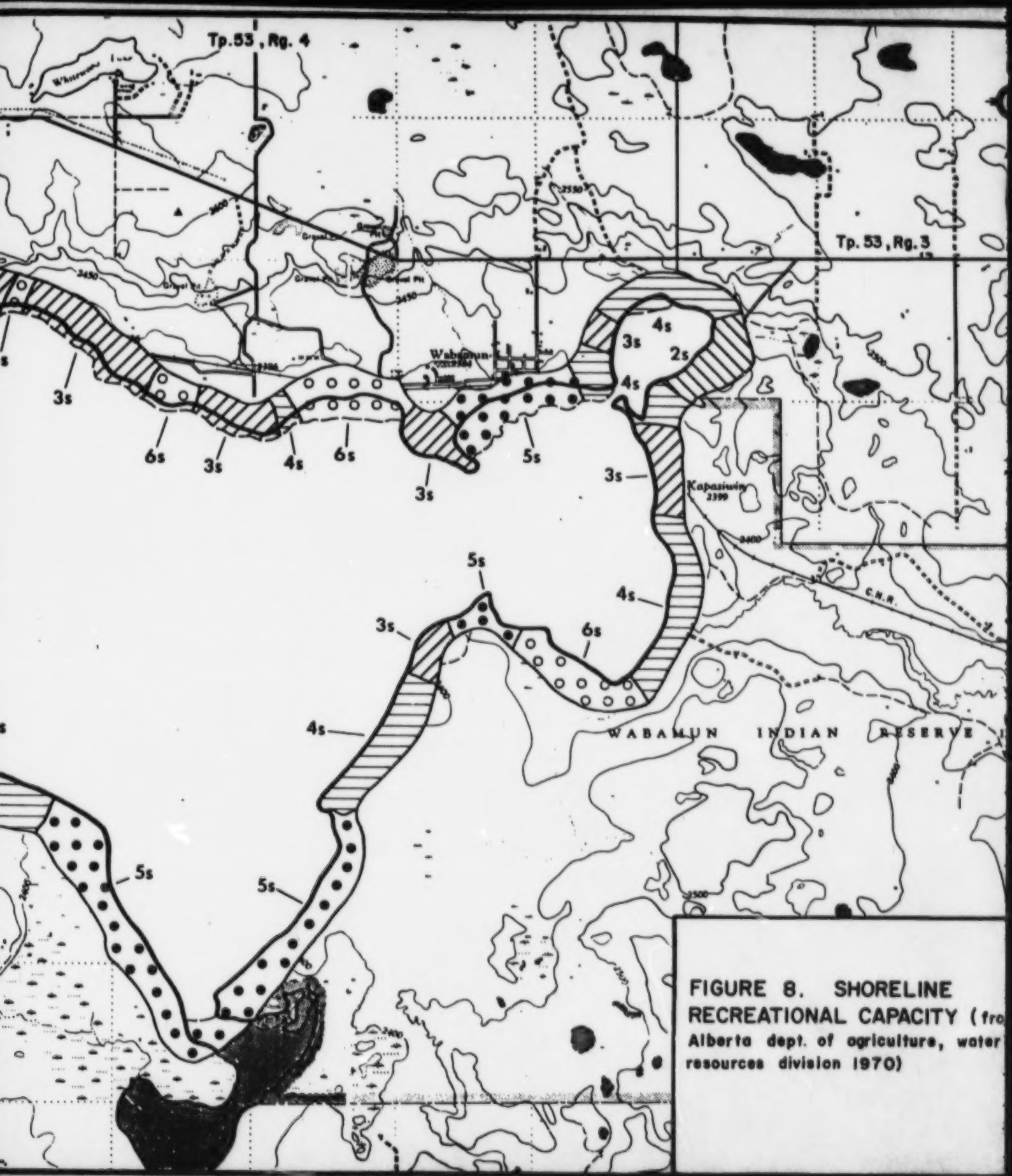


FIGURE 8. SHORELINE RECREATIONAL CAPACITY (fro
Alberta dept. of agriculture, water resources division 1970)

the Class 3 shoreline is committed to recreation. Table 5 shows the untilization of the shoreline for recreation by C.L.I. class.

Table 5. Lake Wabamun subdivision frontage, by CLI class. (from Water Resources Div. 1970).

CLI Class	Subdivision frontage m	Frontage not yet subdivided m
2 - S	1 657.5	0.0
3 - S	13 106.5	6 575.8
4 - S	4 139.2	16 734.1
5 - S	0.0	9 157.1
6 - S	1 460.0	6 232.6

F. INDUSTRIAL DEVELOPMENT

The main industrial developments are, as mentioned previously, two TransAlta generating plants and the Whitewood and Highvale coal mines associated with the plants. The only other sizeable industry is the Building Products of Canada Ltd. plant located on the Wabamun outlet canal.

Property owners along the southwestern shore in the south Seba - Betula Beach area recently became very concerned by TransAlta's application to the ERCB (June 1980). TransAlta wished to extend the permit boundary of the Highvale Mine Site towards the lake to include an additional 158.6 ha, which could bring the coal mining operation to within 70 m of existing residential development and to within 125 m of the lake itself (Makale and Kyllo Planning Associates Ltd., 1980).

Area residents organized the Wabamun Home Owners Association (WHOA) in July 1980 to oppose the TransAlta proposal, their main concern being

reduction of the quality of life. Specific concerns voiced at ERCB hearings included mine impacts on the lake, effects of stream diversions on watersheds, dust, noise, aquifer effects, reduction of value of beaches, property damage by blasting, and traffic hazards (WHOA 1980).

In March 1981 the ERCB turned down TransAlta's mine extension application.

F. AGRICULTURE

The area around Lake Wabamun has been fully settled for some time. Farm size and acreage of improved land have increased over the years; average farm size now is about 138 ha, and about 40% of the watershed area is improved land (Reid, Crowther 1973).

The principle crops are barley, forage, oats and wheat. Within the last 30 years the acreage of forage crops, grasses and legumes have increased significantly, as have the number of livestock (Wabamun Lake Task Force 1971).

G. FISHERY

The fishery resource has long been an important aspect of Lake Wabamun. Lake Whitefish (Coregonus clupeaformis) and Northern Pike (Esox lucius) are species of importance to both commercial and sport fishing. The other species which are occasionally caught, but are of negligible commercial importance, are Yellow Perch (Perca flavescens), Ling or Burbot (Lota lota), and White Sucker (Catostomus commersonii).

1) COMMERCIAL FISHERY

Commercial fishing has occurred in Lake Wabamun since at least 1917 (Dempsey 1942) however accurate records date back only to 1944. Whitefish comprise 96% of the commercial catch (Lane 1970a).

Between 1917 and 1941 over 2 730 000 kg of whitefish were taken by commercial winter net fishing. Intensive fishing pressure in the late 1930's depleted the resource so badly that the lake was closed to net fishing in March 1941 until the winter of 1943-44 (Dempsey 1942, Miller and Paetz 1952). The closure allowed the fishery to recover. Production was fairly stable from 1944 to 1954. In the winter of 1955-56 a peak harvest of 479 000 kg of whitefish was recorded. However, following that record harvest, the yield declined drastically, probably due to overfishing and reduced fish size (Land 1970a), forcing a closure in 1961-62 (Zelt 1981). After a few years of little or no fishing pressure, the yields increased to a level of approximately 22 700 kg annually, or about one seventh of the 1944-61 annual average (Lane 1970a).

In 1972, the increased popularity of sport fishing necessitated the allocation of quotas to each user group. Historical commerical harvest

indicated that total annual whitefish production in the lake should be about 113 636 kg, which in 1972 was allocated as follows:

Commercial fishery	34 091 kg
Sport fishery	68 182 kg
Indian domestic	11 363 kg
	113 636 kg

Lack of license limitation resulted in the commercial quota being exceeded, so in an attempt to mitigate this, the length of the season was reduced from 4 days (1975) to 2 days (1976) to 1 day (1977) (Zelt 1981). The commercial fishing day occurs between March and May (IEC 1979).

Northern pike are also harvested commercially but are secondary in importance to whitefish. The peak season for pike was 1958-59 when 25 187 kg were taken. During the 1960's the average catch declined to about 545 kg annually (Lane 1970a), and is now about 2 722 kg per year (IEC 1979). At present, no commercial licenses are issued for pike, reserving it for the sport and native fishery.

Table 6 presents commercial fishing records for all species for the years 1944 through the winter of 1978-79. Commercial fishing presently accounts for only about 30% of the total catch (IEC 1979).

Table 6. Commercial Catch Summary For Lake Wabamun 1944 - 1979.

Year	No. of Licences	Species of Fish Kg Suckers	Ling	Mixed	Pike	Perch	Whitefish	Total Catch
44/45	791				318		144 336	144 653
45/46	997				277		153 498	153 725
46/47	1 299					383	241 669	242 051
47/48	1 422						167 431	167 431
48/49	1 163						136 320	136 320
49/50	1 049				3 676		125 926	129 603
50/51	1 504			2 946	2 807		136 260	142 013
51/52	1 773			1 435	3 660		112 746	117 841
52/53	1 365			619	1 237		62 889	64 746
53/54	1 222			177	827		90 218	91 222
54/55	1 066				744		183 012	183 756
55/56	910				170		479 002	479 172
56/57	1 188				463		204 911	205 373
57/58	1 314			635	1 209		151 545	153 389
58/59	977			16 043	25 187		113 527	155 210
59/60	817			5 740	19 602		55 081	80 423
60/61	610			6 919	20 062		57 331	84 312
61/62	Closed Season							
62/63	106			391	485		1 442	2 318
63/64	66				381		3 205	3 586
64/65	Closed Season							
65/66	137			454	748		40 824	42 026
66/67	72	181	308		113		10 433	11 036
57/68	77	779	510		548		23 633	25 475
68/69	10	1 631	1 783		2 391		20 717	26 522
69/70	14	2 956	3 443		870		25 355	32 624
70/71	10	2 867	1 184		3 397		18 154	25 601
71/72	8	2 406	874		1 518		23 976	28 774
72/73	22	6 657	2 555		3 625		47 810	60 647
73/74	9	3 526	1 415		615		15 088	20 645
74/75	26	4 734	2 935		984		83 272	91 925
75/76	102	420	124		83		116 609	117 236
76/77	202	1 649	1 351		553		80 817	84 370
77/78	190	1 472	646		2 295		63 887	63 301
78/79	400	-	-		3,629		52 835	56 464

Data modified from Alberta Fish and Wildlife-Fisheries Division 1979.

2) SPORT FISHERY

The sport fishery is a far more valuable resource than is the commercial fishery, not only for the recreation provided for a great many people but for the monetary benefit derived from the support industry. Lane (1970b) estimated that the sport harvest exceeded the commercial harvest (all species) by 242.9% on a pounds per acre basis.

Ice fishing has become very popular in the last 20 years. The winter fishery is dominated by whitefish and is more successful than the pike-dominated summer fishery (Lane 1970b, Lane and Lynch 1969).

Pike and perch are caught all year round in the east end. Larger than average pike are reported from the power outlet canal area (Lane 1970b, Lane and Lynch 1969).

From a six month winter creel survey for the period November through May 1968-69, Lane (1970b) estimated that 44 000 man-days were spent in winter fishing and anglers caught a total of 61 479 kg of whitefish, 28 743 kg of pike, and 700 kg of perch during the survey period. The whitefish yield was estimated as 6.78 kg/ha and 3.17 kg/ha for pike. The yield per unit effort was calculated to be 0.8 fish per hour. Nearly 80% of the catch was whitefish.

An Alberta Fish and Wildlife winter creel survey in 1979 (Zelt 1981) indicated an estimated total of 15 632 anglers spent over 55 000 hours from January through March, and caught a total of 15 242 kg of whitefish for the three month period with almost 10,000 man-days spent in March. The catch per unit effort was between 0.47 and 0.65 (IEC 1979, Zelt 1981).

A 1969 summer creel survey (May through September) (Lane and Lynch 1969) indicated that approximately 8200 anglers spent 31 000 hours, and caught 12 700 pike weighing about 20 000 kg.

Neither whitefish nor pike are stocked at Lake Wabamun. Both populations are in good condition and have a stable age structure (E. Stenton, Alberta Fish & Wildlife Division per community).

At present, the annual provincial quota for whitefish sport fishing is set at 68 040 of (IEC 1979).

3) NATIVE FISHERY

Whitefish is the species most utilized by the Paul Band Indians. The provincial quota for Lake Wabamun for use by reserve Indians is set at 11 340 kg of whitefish per year. It is believed that this is not being fully utilized, although no yearly catch data are available (IEC 1979).

IV. POWER GENERATION

A. DESCRIPTION OF PLANTS

Proximity to sources of both coal and cooling water make Lake Wabamun an attractive site for thermal-electric generating plants. TransAlta operates two power plants at the lake (Fig. 9).

The Wabamun plant, on the north shore near Point Alison and Wabamun village, began operation in 1956. It has four units, three of which are coal fired and the other is gas fired, for a total generating capacity of 569 MW. Coal is obtained from the Whitewood surface mine, just north of Highway #16. The plant burns about 4110 t of coal per day (Railton, pers. comm.)

The Sundance plant, located on the south shore near Goosequill Bay, began operation in 1970 and presently has six coal-fired units for a total generating capacity of 2100 MW. Coal consumption is about 19 833 t/d. Coal is obtained from the Highvale surface mine south of the lake (Railton, pers. comm.)

In the Wabamun plant's once thorough cooling system, lake water is pumped through condensers and returned to the lake through an open canal at an elevated temperature. A similar system was used at the Sundance plant until late 1975 when a closed system cooling pond was put into operation. The North Saskatchewan River water is used for makeup and blowdown, making this plant independent of the lake for cooling.

Fly ash, fine particles that leave the boiler with the flue gas, are collected by electrostatic precipitators to reduce particulate emissions to the atmosphere. Bottom ash (particles too heavy to go up with the flue gases) is collected in water hoppers and the slurry is disposed of in an ash lagoon. At the Wabamun plant, the 1971 ash lagoon, located

FIGURE 9. LOCATION OF WABAMUN AND SUNDANCE POWER PLANTS ON LAKE WABAMUN

west of the plant, is used to remove settable solids. It also receives some runoff from the Whitewood mine. The ash lagoon effluent is decanted via a culvert and is discharged to the lake through a canal (Dowhaniuk, 1977).

Each generator unit is equipped with two circulating water pumps, one of which is shut down in the winter resulting in less condenser through-flow in the winter although the total heat discharge remains the same (Reid, Crowther 1973). Mean monthly powers loads are higher in winter than in summer (Allen and Gorham 1973).

B. THERMAL DISCHARGE

The total heat discharged from the Wabamun plant is about 181 x 10^8 kcal/ (Beak 1980). The average condenser flow rate is about 29,200 L/s (1031 cfs) in the summer and 14 600 L/s (515 cfs) in the winter (Beak 1980). In the summer the discharge cooling water is about 10°C warmer than the ambient lake water, in the winter it is about 15°C warmer (Beak 1980). The temperature differential may be as much as 20°C at times (Nursall and Gallup 1971). Provincial standards require that discharged cooling water must not be more than 3°C above ambient.

Prior to 1975, the total heat discharged from the Sundance plant was about 164 x 10^8 kcal/day, the average condenser flow rate was about 6500 L/s (226 cfs) in the summer and 4600 L/s (162 cfs) in the winter (Beak 1980). The temperature differential between intake and outlet averaged 10°C in the summer and 18°C in the winter (Beak 1980). Allen and Gorham (1973) reported maximum temperature differentials of 11°C in the summer and 22° in winter.

Surface thermal discharge such as at Wabamun (and formerly Sundance) flows out from the open canal and spreads out to form a thin heated

layer on the surface of the lake separated from the ambient lake water by a sharp thermocline.

There have been a number of investigations into the physical nature of the thermal plume including:(1) Temperature and dissolved oxygen in the mixing zone (Gallup and Hickman, in Gallup [ed.] 1971, Gallup and Hickman 1973); (2) temperature; (3) dissolved oxygen and water chemistry (Gallup and Hickman 1975); (4) temperature regimes (Klarer, Hickman and Gallup 1973); (5) remote sensing of plume distribution (Neilson 1970); (6) evaporation investigations (Nursall, Nuttal and Fritz 1972, Sauleslija 1976, Hage 1978); (7) boundary layer fluxes above the plume (Hogg 1973); (8) heat and water vapor exchanges (Hage, Honsaker and Nuttall 1973); and (9) thermal discharge monitoring (Shewchuk 1970).

The mechanisms of dispersion of a thermal effluent are:

1. Convective spread of the effluent from an initial dilution zone over the surface of the receiving water;
2. Mass transport of the effluent by ambient currents;
3. Diffusion due to turbulence;
4. Evaporative cooling (Shewchuk 1970).

The contribution of each of these factors to the cooling of the Wabamun thermal plume have not been quantitatively defined.

Saulisleja (1976) estimated that slighly less than one half of the excess thermal energy of the warm stream is lost by evaporation and the remainder of the heat is lost by radiation and sensible heat transfer. Reid, Crowther (1973) calculated that about one third of the excess heat is lost by evaporation and radiation and the remaining two thirds is lost through mixing at the hot-cold interface of the lake water.

Hogg (1973) found that fluxes of heat and water vapor above the heated plume were approximately five times greater than above the unheated lake in August; in winter the difference would be much greater.

The changing size, shape and volume of the plume make it difficult to estimate the average flux (Hogg 1973).

The thermal plume is greatly influenced by meteorological conditions. The distribution area and volume of the plume vary with wind speed and direction as Figure 10 exemplifies. Strong winds may overcome the thermal stratification and cause complete mixing (Nursall and Gallup 1971, Nursall et al. 1972). The Sundance plume, a more exposed area, experienced a greater variation in size, shape and dissipation than the Wabamun plume, which is partially protected from winds by Point Alison (Klarer et al. 1973).

The discharge affects a relatively small and sharply circumscribed area of the lake ranging from 5 to 10% of the lake surface area for the Wabamun plume. Probably less than 2% of the total lake volume is affected (Nursall et al. 1972).

The most marked effect of the thermal effluent is the maintenance of an ice-free area all winter. This open water area has a high evaporation rate due to the low atmospheric water vapor pressure at low air temperatures. This enhanced evaporation caused concern that the water balance and level of the lake would be altered (Nursall, in Gallup (ed.) 1971) but lake levels have not indicated this.

Partial recycling of heated water occurs at the Wabamun plant (and formerly at Sundance) due to natural currents (Neilson 1970) but the water is cooled almost to ambient temperature by the time it reaches the inlet canal (Nursall et al. 1972). The surface nature of the discharge results in minimal mixing with deeper waters and cooling is rapid (Nursall et al. 1972).

Both plants' cooling systems were designed to draw intake water from the deeper portion of the lake, where summer temperatures are cooler, as

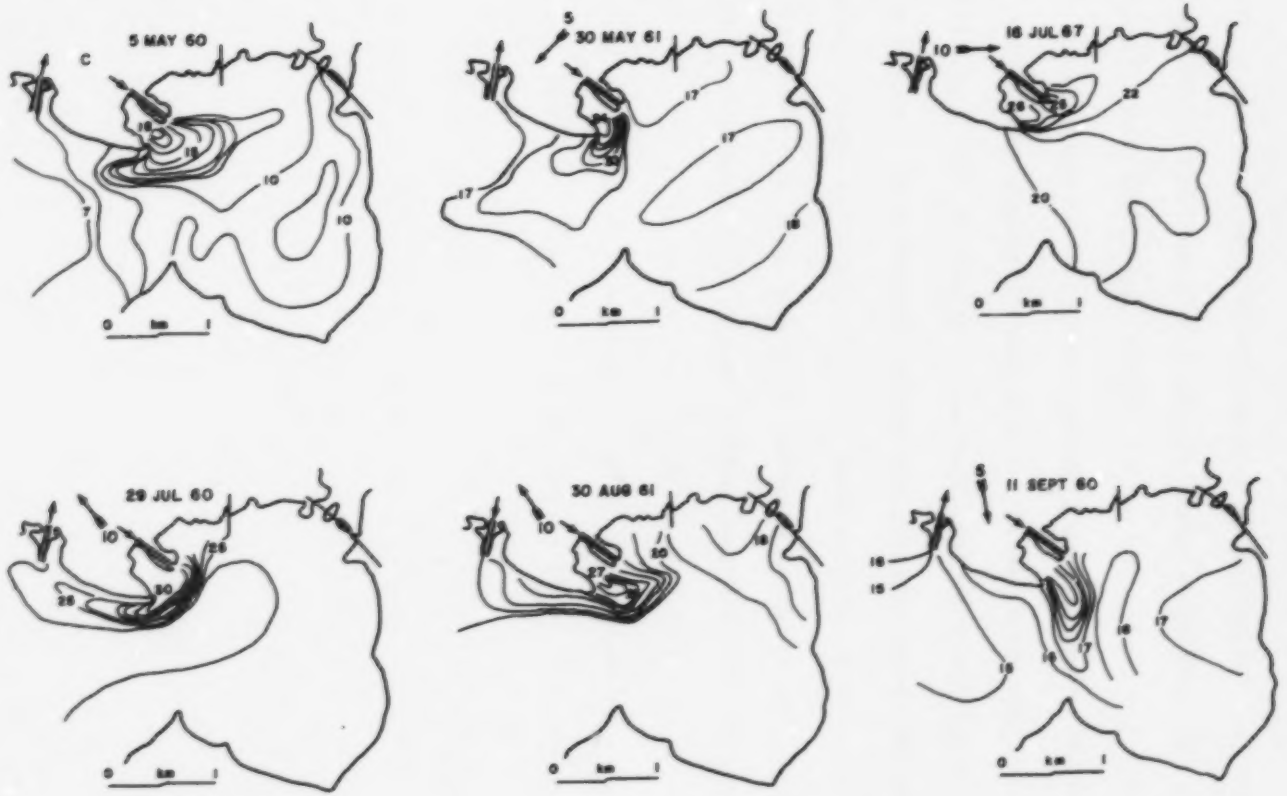


FIGURE 10. DISTRIBUTION OF SURFACE TEMPERTURES ON SELECTED DATES, LAKE WABAMUN.
(from Nursall and Gallup 1971.)

this is important to the plant's efficiency. The discharge canals were placed on the opposite side of the plant to prevent recirculation of the warm water (although Neilson (1970) has shown that some recycling does in fact occur). The result of this design is that the cooling water is discharged into shallow areas of the lake, contributing to biological changes. Had the intake and outlet canals been reversed, biological problems may have been reduced (Reid, Crowther 1973).

In 1973 the ERCB decided that TransAlta must construct a 263 ha cooling pond for the Sundance plant units 1 and 2 by July 1975, to prevent heated water entering the lake. TransAlta was granted approval to construct a 480 ha cooling pond that accomodates the present six generating units. Since December 1975 this pond has been used as the cooling facility at Sundance making the plant independent of Lake Wabamun.

C. ALTERNATIVE USES OF EXCESS HEAT

Shaw et al. (1979) evaluated the potential for a commerical greenhouse heated by thermal discharge but found it uneconomical. Problems encountered in the pilot project were: (1) inadequate water temperature, (2) humidity causing winter ice-up and; (3) a high energy cost for fans and pumps.

Aquaculture is another possibility to make use of the thermal effluent. According to Ferguson, Harrison et al. (1974b) who evaluated the potential for aquaculture in Alberta, Lake Wabamun is in an area classified as "best" for fish culture and "second best" for freshwater shrimp culture.

Since 1979 a fish farmer has been using the Sundance plant cooling water to raise rainbow trout. He raises about 450 000 fish from 2 cm fry to 15 to 20 cm adults from October through April in tanks through which the warm water is pumped. No problems have been encountered with water quality, oxygen levels or disease (Fred Williamson, pers. comm.).

V. PHYSICAL AND CHEMICAL CHARACTERISTICS

A. TEMPERATURE

The normal temperature regime in Lake Wabamun, in areas unaffected by the thermal effluent, consists of winter ice cover and inverse stratification from approximately November through April and isothermal conditions in spring and fall with complete mixing by wind and wave action. Occasionally during the summer a thermocline may develop, but due to the lake's shallowness and exposure to wind this is transient (Gallup ed. 1971, Gallup and Hickman 1973, 1975). The lake warms rapidly in the spring in contrast to much slower cooling in the fall (Klarer 1973). Beak (1980) found a thermocline in some years only at a 7 m deep site. Rasmussen (1979), who sampled from 1972 through 1975, never detected a thermocline even in the lake's deepest portions.

The normal surface temperature patterns are much more complicated and unpredictable in the discharge plume area. The warm plume forms a thin surface layer over a layer that is close to ambient lake temperature (Nursall and Gallup 1971). The plume layer, approximately 0.5 m deep, becomes thinner with increasing distance from the outlet. Flow direction and speed of dissipation of the plume are dependent on wind speed and direction (Gallup and Hickman 1975).

Shallow areas close to the discharge outlet have a more consistent temperature regime than more distant areas of the discharge. Gallup and Hickman (1975) recorded August maximum surface and bottom temperatures of 31°C and 30°C at a shallow (1 m depth) station at the mouth of the Wabamun outlet canal. The surface temperature was 7°C higher than ambient temperatures. Beak (1980), at a 2.5 m deep sampling station 75 m from the Wabamun outlet, recorded surface temperatures ranging from

11°C to 31°C. The mean daily temperature differential between the Wabamun intake and outlet canals is greatest in winter; for January 1975 Beak (1980) recorded an average rise of 14.4°C from intake to outlet.

Deeper and more distant sampling stations in the plume area showed greater wind influence. Occasionally warm water may be injected deeply into the water column. Depending on the wind, rapid surface cooling may occur (Gallup and Hickman 1975). In winter, the ice-water juncture is not constant but shifts depending on heat output, wind, and weather conditions (Nursall and Gallup 1971).

Even within a 24-hour period temperature may vary considerably (Gallup and Hickman 1973). These temperature fluctuations can be significant to the flora and fauna living within the thermally-affected zone since they are subject to much greater temperature variations, even within a single day, than normally occurs in the lake (Gallup and Hickman 1973).

Beak (1980) summarized the physical effects of proximity to thermal discharge as follows:

1. Increased temperatures at all depths, especially in winter;
2. Increased seasonal stability;
3. Increased weekly fluctuation;
4. Increased statification;
5. Decreased inverse stratification;
6. Over-winter "warm spells" on the bottom;
7. Shorter "winter";
8. Extreme temperatures not as low in plume area;

B. DISSOLVED OXYGEN

Prior to the work of Gallup and Hickman (1973, 1975), dissolved oxygen was measured only irregularly; measurements did not give indications of seasonal changes (Reid, Crowther 1973). Dempsey (1942) reported that although dissolved oxygen declined near the bottom (10.7 m) it was not below the lethal limit for fish and the lake was well-oxygenated due to its shallowness and wind mixing. A Fish and Wildlife Division report investigating poor whitefish condition (Miller and Paetz 1952) suggested that, based on oxygen content and dredge samples, a winter kill of bottom fauna due to anoxia had occurred in 1951-52. Thomas (1960) reported that the lake was in excellent winter condition with ample dissolved oxygen right to the bottom.

Gallup and Hickman (1973) state that in general, dissolved oxygen concentrations in Lake Wabamun are ample throughout the year for the support of aquatic organisms. Surface water is usually oxygen-saturated; values of less than 5 ppm usually occur only within the bottom 30 to 60 cm and at certain times of the day (Gallup and Hickman 1973).

Dissolved oxygen studies have indicated the importance of both wind-induced water mixing and internal lake currents. Gallup and Hickman (1973, 1975) found that surface water dissolved oxygen concentrations under ice cover fell in February and March and again in November and early December. However, later in December dissolved oxygen rose to 100% saturation, which could only be explained by internal current systems bringing highly-oxygenated water from the open-water area. Gallup and Hickman (1975) suggested that the consistently high dissolved oxygen levels observed in Lake Wabamun may

be atypical for a lake of this type that does not receive thermal effluent, since the ice-free area coupled with the internal currents probably contribute to increased oxygen concentration in the whole lake.

Supersaturation of dissolved oxygen of the surficial water in the plume area is usual. Values of up to 140% saturation have been recorded in the winter. This is because cold (0-1°C) water near the oxygen-saturation point passes through the generators and becomes supersaturated as it is warmed, since warmer water has reduced oxygen-holding capability (Gallup and Hickman 1975).

Gallup and Hickman's (1971) diurnal study indicated that great daily variations of dissolved oxygen in the plume area occurred. The highest oxygen levels were observed in the late afternoon and lowest levels occurred at night. However, pre-dawn oxygen increases in the absence of wind suggested internal current systems.

Macrophyte growths can cause shading, which results in the decomposition of organic matter, lowering dissolved oxygen levels and increasing biological oxygen demand. Gallup and Hickman (1975) found that this situation arose for short periods in dense weed growths within the thermally-enriched area.

C. WATER CHEMISTRY

Many researchers in the early 1970's conducted water chemistry analyses of Lake Wabamun. Mean values for a number of parameters have been summarized in Table 7. A note of caution in interpreting these results is in order. Nutrients are usually present in lake water at very low levels, often at or below the detection limit of the water analysis techniques that were employed at the time. Great care must be taken to avoid contamination of samples. Analytical methods have improved to such an extent that much lower levels can be detected and more precisely determined. This is especially true for phosphorus which is probably the major nutrient of concern at Lake Wabamun. Thus the value of these earlier nutrient analyses is questionable (P. Mitchell, pers. comm.).

For most of the parameters, lake water quality is satisfactory, usually meeting or exceeding the Provincial Surface Water Quality Standards. Exceptions noted are pH, phosphates and phenols. Reid, Crowther(1973) surmised that there were natural causes for the high pH (photosynthesis) and phenolic concentrations (decaying vegetation).

From Table 7 discrepancies in the phosphate and other values are noted, which Reid, Crowther (1973) attributed to differences in analytical technique. If this deduction was correct, phosphates are within provincial standards. The most current data from the Alberta Envirnoment study (Mitchell et al. 1981) indicate mean total phosphorus is 0.030 mg/L, which agrees reasonably well with observed levels of eutrophication.

There are also discrepancies in the reported values for heavy metals, most notably the high values for lead (0.11 mg/L to 0.14 mg/L)

Table 7
Lake Wabamun Water Quality Comparison

Average Values (units are mg/L unless otherwise no

Reference	PH	Total Alkalinity (as CaCO)	Total Hardness	Ca Hardness	Orthophos-phate	To Phos
Allen 1973	8.6	150			0.01	
Beak 1974-1978 Kapasiwin						0.(
Beak 1974-1978 Sundance						0.(
Calgary Power 1972 East[1]	8.6	207				0.(
Calgary Power 1972 West[1]	8.6	211				0.(
Calgary Power 1979 East[2]	8.6	194	133			0.(
Dept. of Environment 1970-1972[1] East[3]	8.6	188	115			0.2
Dept. of Environment 1970-1972[1] West[3]	8.4	193	116			0.2
U of A 1971[1]	8.9	168			<0.05	
Gallup and Hickman 1975 WO[4]			127	57.4	$<\frac{0.015^{6}}{0.06}$	
Gallup and Hickman 1975 SC[5]			124.8	56.9	$<\frac{0.012^{6}}{0.08}$	
Horkan 1971 Kapasiwin	8.6	192	124	67.5	0.24	0.0
Horkan 1971 West	8.6	196	129	71.5	0.20	0.0
Klarer 1973	8.92	162.8	120		0.020	
Moton 1974	8.77	174.1	127	59	0.018	
Alberta Surface Water Quality Objectives	6.5-8.5					Tota <0.1

1. From Reid, Crowther 1973. (Calgary Power now TransAlta Utilities)
2. From IEC 1979.
e. Average of three sites.
4. Wabamun power plant outlet canal
5. Sailing Club
6. Range presented only because initial method had an accuracy to 0.05 mg/L and values were below this level except for a few occasions.

Table 7
Lake Wabamun Water Quality Comparison

Average Values (units are mg/L unless otherwi

Reference	PH	Total Alkalinity (as CaCO)	Total Hardness	Ca Hardness	Orthophos-phate	Tot Phosp
Allen 1973	8.6	150			0.01	
Beak 1974-1978 Kapasiwin						0.07
Beak 1974-1978 Sundance						0.07
Calgary Power 1972 East[1]	8.6	207				0.07
Calgary Power 1972 West[1]	8.6	211				0.01
Calgary Power 1979 East[2]	8.6	194	133			0.03
Dept. of Environment 1970-1972[1] East[3]	8.6	188	115			0.21
Dept. of Environment 1970-1972[1] West[3]	8.4	193	116			0.2
U of A 1971[1]	8.9	163			<0.05	
Gallup and Hickman 1975 WO[4]			127	57.4	$<\frac{0.015^{6}}{0.06}$	
Gallup and Hickman 1975 SC[5]			124.8	56.9	$<\frac{0.012^{6}}{0.08}$	
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Alberta Surface Water Quality Objectives	6.5-8.5					Tota <0.1

1. From Reid, Crowther 1973. (Calgary Power now TransAlta Utilities)
2. From IEC 1979.
e. Average of three sites.
4. Wabamun power plant outlet canal
5. Sailing Club
6. Range presented only because initial method had an accuracy to 0.05 mg/L and values were below this level except for a few occasions.

Nitrate	Silicate	Iron	Chloride	Sulphate	Calcium	Sodium	Magnesium	Potassium
0.03	2.5	0.05	2.3	26				
0.024								
0.028								
0.7		0.24		20	25	39	14	
0.9		0.12	2.9	22	26	37	13	
0.150		0.029	3	30	2.55	43	13.5	7.33
0.1-0.7		<0.1			26	41	13	7.9
0.1		0.1			27	42	13	7.9
0.05		0.13						
			1.8	28.6				
			1.8	29.3				
	2.9	0.13		35				
	3.1	0.09		85				
0.03	2.1	0.05	2.18	26				
0.04	1.74	0.05	2.0	30				
1.0		0.30				75 Cations		

Table 7A
Lake Wabamun Water Quality Comparison

Average Values (units are mg/L unless otherwise noted

Reference	Total Dissolved Solids	Conductivity µs/cm	Turbidity JTU	BOD	Phenols	Ammon
Allen 1973		390				
Beak 1974-1978 Kapasiwin			2.17			
Beak 1974-1978 Sundance			2.70			
Calgary Power 1972 East[1]	316					0.3
Calgary Power 1972 West[1]	320					0.2
Calgary Power 1979 East[2]	242		3		<0.002	0.0
Dept. of Environment 1970-1972[1] East[3]	296		2.8	2.1	0.005	
Dept. of Environment 1970-1972[1] West[3]	275		2	1.8	0.003	0.2
U of A 1971[1]						
Gallup and Hickman 1975 WO[4]	232	378.3				
Gallup and Hickman 1975 SC[5]	230.9	373.7				
Horkan 1971 Kapasiwin						
Horkan 1971 West						
Klarer 1973	228.1	350	11			
Noton 1974	232	383				
Alberta Surface Water Quality Objectives			25 over natural		0.005	Tota <1.0

1. From Reid, Crowther 1973.
2. From IEC 1979.
3. Average of three sites.
4. Wabamun power plant outlet canal
5. Sailing Club
6. Range presented only because initial method had an accuracy to 0.05 mg/L and values were below this level except for a few occasions.

Cobalt	Copper	Manganese	Nickel	Cadmium	Chromium	Lead	Mercury	Zinc
0.02	0.006	0.03	0.04	;	0.01	0.11	0.002	0.04
0.03	<0.005	0.02	0.05	< 0.005	< 0.01	0.14	0.0001	0.04
< 0.001	0	0.025	0.002	0	0	< 0.003	0	0
0.004	0.006	0.02	0.04	0.001	0.002	0.02	0.0005	0.017
	0.02	0.05		0.01	0.05	0.05	0.001	0.05

reported by Calgary Power (1972). This is probably due to analytical error; the more recently reported value of less than 0.003 mg/L (Calgary Power 1979) is more likely correct.

A comparison of past and present data with provincial standards indicates that water quality has not changed during the last nine years (IEC 1979). It appears that water quality in the area of most heavy metals and phenols has improved, although this may actually represent an improvement in analytical techniques.

There does not appear to be bacterial contamination of the water. Total coliform count data from several Alberta Environment surveys in 1970 to 1972 (Table 8) ranged from 4.3 to 15.2 per 100 mL, well below the maximum of 1000 per 100 mL allowable in water used for direct contact recreation.

Table 8. Bacterial contamination in Lake Wabamun; Alberta Environment Surveys

Reference	Total Coliform/100 mL	Fecal Coliform/100 mL	Standard Plate Count/mL
Masuda 1972	4.3	0.1	132
Shewchuk 1970	9.05	2.25	200
Simpson 1970	15.2	2.0	2187

D. SEDIMENTS

An understanding of lake sediment dynamics is essential to lake management strategies designed to reduce productivity (Allan and Williams 1978). Limnogeological studies can provide a framework for the integration of results of other research, and can provide information on evolutionary trends of the lake and surrounding ecosystem, on chemical cycles and on the energy regime within lakes (St John et al. 1973). Sediments provide a fossil record of the lake's trophic status in the past, of the type of surrounding vegetation, and give information about past climatic regimes.

In many deep oligotrophic lakes sediments act as a nutrient sink, but in shallow eutrophic lakes, such as tnose in the prairies, sediments play a more dynamic role. The influence of sediments is greater in lakes where the surface area of the sediments is large in proportion to the column of water. Thus level portions of the basin profile have more influence on the chemical stratification than do steep portions (Ruttner 1963). Lake Wabamun, being shallow, would thus have a larger ratio of sediment surface area to lake volume than would a deeper lake.

The surface sediments of Lake Wabamun are loose, unconsolidated, and mixed by wind generated wave action and internal currents. This complicates the collection and dating of the upper more recent sediments (Hickman, pers. comm.). Average water content of Beak's (1980) samples of the top 20 cm of sediment was 77.8%. Lake Wabamun sediments are thickest in the west end, where they are up to 20 m deep and date back approximately 9000 years (Allen, minutes of LWWAC meeting, Feb. 24, 1981).

Sediments tend to act as a nutrient sink or reservoir since they take up nutrients faster than they release them, and any material in the water that precipitates is incorporated into the sediments (Allen 1981). Phosphorus, an essential but relatively scarce element, is often the limiting nutrient for primary productivity in lakes (Cole 1975). Phosphorus release from the sediments tends to be greater under anoxic conditions (Cole 1975). However, despite Lake Wabamun's year-round oxygenated condition, the loose nature of the sediments and the great degree of wind mixing cause resuspension of sediment particles which may make more phosphorus available to algae (P. Mitchell, pers. comm.).

Barica (1974) showed that in small, shallow, self-contained pot-hole lakes in southwestern Manitoba internal cycles of nitrogen and phosphorus occur. Nutrients were released during anoxic conditions in the winter and following oxygen-depleting summer algal blooms. Ammonia and phosphate were assimilated by algae, and dissolved organic nitrogen and phosphorus were produced by both living and decomposing algae. The nutrient cycles were closed and independent of external sources.

Allen (1973) sampled Lake Wabamun sediments to a depth of 50 cm for nutrient analyses. He described the lake bottom as consisting of a fine flocculent ooze of a light brown color, usually over 2 m deep. He found phosphate levels were strongly stratified and concentrated in the upper 20 cm of sediment. Highest phosphate levels in sediments were found at depths below the photic zone (4 m).

Allan and Williams (1978) examined various forms of phosphorus and iron in the sediments of a number of prairie lakes, including Wabamun, with respect to trophic status and lake rehabilitation (Table 9). They

found Lake Wabamun sediments had a high organic carbon content (17.6%), and a high total phosphorus content (1126 µg/g) of which 58.7% was organic P.

Table 9. Sediment analysis for organic carbon and phosphorus, Lake Wabamun[a] (From Allan and Williams 1978).

Organic C	17.2%
Total P	1126 µg/g
Organic P	661 µg/g
Inorganic P	465 µg/g
Apatite	258 µg/g
NAIP[b]	185 µg/g
CBDP[c]	156 µg/g
Organic C/Organic P	260

a. Sample location: north side
b. Non-apatite inorganic P.
c. Na-citrate-bicarbonate-dithionite extract; considered an adequate estimate for available-P.

Culturally eutrophic but originally oligotrophic lakes, such as Lake Washington, have shown good recovery when the cultural nutrient loading was stopped. However, Allan and Williams (1978) suggested that shallow, naturally eutrophic prairie lakes (such as Lake Wabamun) with high sediment concentrations of available phosphorus to depths of at least 15 cm would show slower recovery in terms of reduction of summer productivity, because of the release of available sediment phosphorus back to the water.

In lakes of the Qu'Appelle Valley, Saskatchewan, Allan and Williams (1978) found winter increases of orthophosphate in the water, presumably due, at least in part, to sediment phosphorus regeneration under anoxic conditions. Groundwater contributions were not known. Allan and Williams suggested that a mean internal phosphorus loading rate of 8 to 10 $mg/m^2/day$ was operating in these lakes. However, over the year, external loading from the Qu'Appelle River was far greater (up to 20 times) than overwinter phosphorus recycling.

Allan and Williams characterized lakes most susceptible to phosphorus regeneration as those having high available phosphorus, free iron and a low ratio of available iron to available phosphorus. Elimination of cultural phosphorus loading would probably result in an initial marked reduction in phosphorus regeneration followed by a continuous slower decline in the regeneration rate, rather than the dramatic recovery of the type exhibited by Lake Washington.

Mean water content, phosphorus, nitrogen and pH for Beak's (1980) sediment sampling sites are shown in Table 10. Beak's value of 995 µg/g total phosphorus is comparable to, but lower than that reported by Allan and Williams (1978).

The role of sediments in the nutrient budget of Lake Wabamun was examined by Hamilton and Reynoldson (1981). Preliminary results indicate significant quantities of biologically available phosphorus in the sediments, phosphorus release to the overlying water, and significant phosphorus loading due to resuspension of flocculent bottom material.

Table 10. Mean Composition of Lake Wabamun sediments (corrected for moisture content). (Adapted from Beak 1980).

	MEAN	RANGE
Water content (%)	77.8	41.1 - 91.0
pH	7.6	7.0 - 8.1
Phosphorus (µg/g dry weight)	995.3	436.4 - 1791.0
Nitrogen (µg/g dry weight)	0.97	0.2 - 2.1

E. WATER QUALITY COMPARISON WITH OTHER PRAIRIE LAKES

Reid, Crowther (1973) estimated Lake Wabamun's trophic status to be between mesotrophic and eutrophic at the east end, and between oligotrophic and mesotrophic in the west end. Gallup and Hickman (1973) characterized it as moderately eutrophic.

Preliminary results of the Alberta Environment eutrophication study (Mitchell et al. 1981) indicate that Lake Wabamun compares favourably with other Alberta Lakes using three criteria for trophic status: total phosphorus, chlorophyll, and Secchi transparency. According to these criteria, Lake Wabamun ranges between mesotrophic and mildly eutrophic at both ends. This is illustrated in Figure 11.

Allen (1973) compared Lake Wabamun, which supports dense macrophyte growths but does not have blue-green algal blooms, with several other lakes, as shown in Table 11. Nearby Lake Isle, comparable in size to Lake Wabamun, is very productive with heavy macrophyte growths and algal blooms. Wizard Lake also produces macrophytes and algal blooms while

TABLE 11. Water analyses for Lake Wabamun and four other lakes in central Alberta (All samples passed through a 0.45μ Millipore filter) (From Allen 1973)

	Wabamun			Wizard[1]	Danard[1]	Pigeon[1]
	Range		Mean			
pH	8.4 - 9.4	8.6	9	8.3	8-10.5	8.2
Orthophosphate, ppm	0.002 - 0.03	0.01	0.41	0.04	0.5	0.01
Nitrate, ppm	0.02 - 0.05	0.03	0.05	0.11	0.05	0.02
Silica, ppm	1.5 - 8.4	2.5	5.8	2.0	0.5	3
Iron, ppm	0.02 - 0.12	0.05	0.15	0.4	0.2	0.22
Sulphate, ppm	18 - 40	26	15	9	3	8
Chloride, ppm	0.11 - 12	2.3	0.46	3.4	10	---
Total alkalinity, as $CaCO_3$, ppm	124 - 180	150	141	---	50	132
Specific conductivity, μmho/cm	----	390	200	---	140	260

[1]The analyses for these lakes are for single samples collected in the summer months.

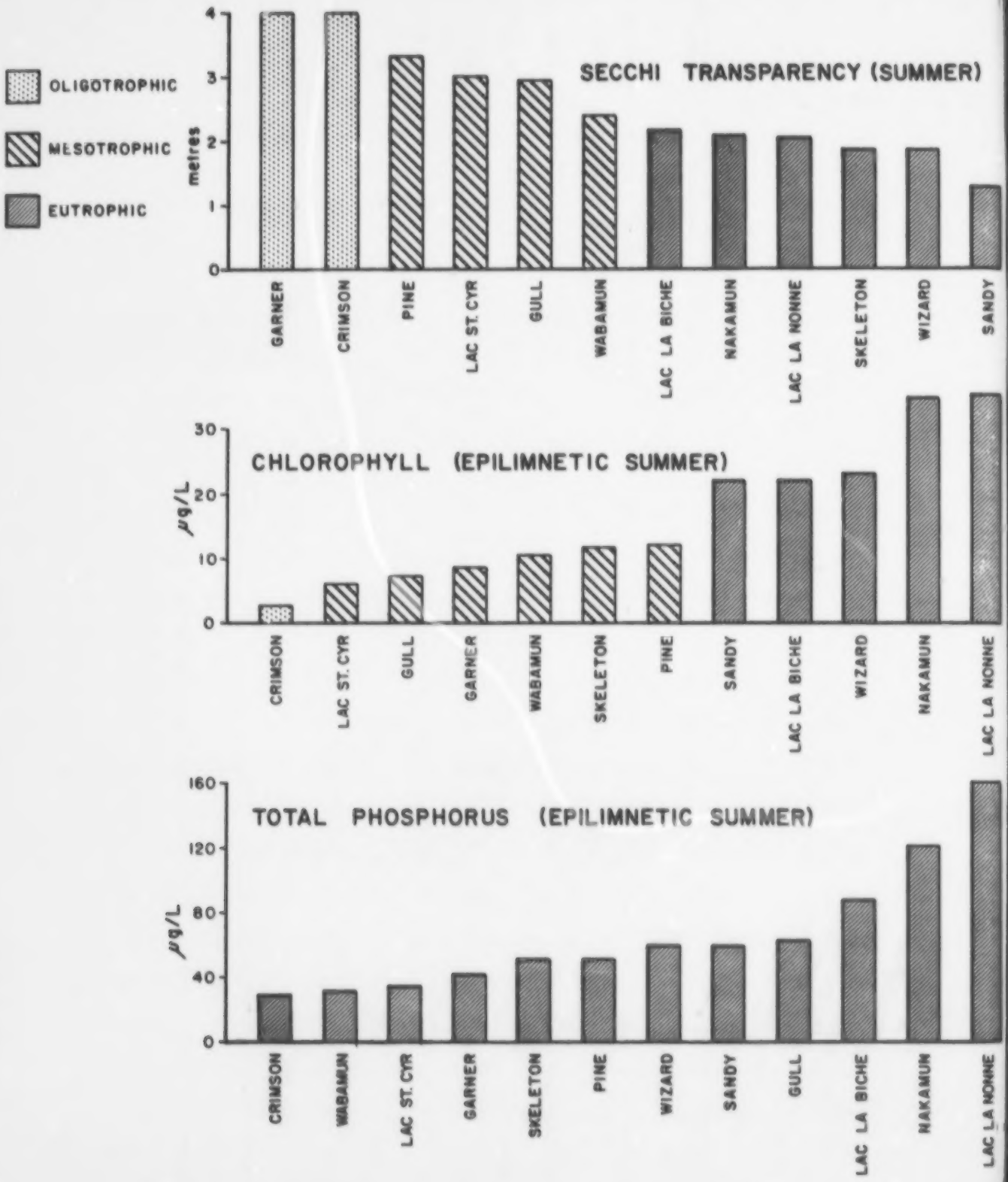

FIGURE II. TROPHIC STATE OF LAKE WABAMUN IN COMPARISON WITH OTHER ALBERTA LAKES (USEPA Criteria)

Alberta ENVIRONMENT
Pollution Control Division
Water Quality Control Branch

Danard Lake has Elodea and algal blooms, and Pigeon Lake does not bloom and has a much lower macrophyte production.

Masuda (1972) surveyed Lake Wabamun, Pigeon Lake and Cooking Lake, to identify and determine the effects of sewage entering the lakes. Both Wabamun and Pigeon lakes had generally acceptable water quality, while Cooking Lake had inferior water quality with many parameters exceeding the Surface Water Quality Standards. Cooking Lake is characteristic of the many saline eutrophic lakes in prairie parkland areas, with sulfate salinity, high pH, high total alkalinity, high conductance and high biological oxygen demand. A summary of Masuda's (1972) results is shown in Table 12.

F. WATER BUDGET

A water budget for the lake includes surface runoff (both stream flow and diffuse runoff), precipitation on the lake surface, surface outflow, lake evaporation, and groundwater inflow and outflow. Each item varies from year to year causing variations in lake level. Items may be measured directly or estimated from models.

A long-term average water balance (Figliuzzi 1979; Mitchell et al. 1981) is presented in Table 13, based on the 1980 hydrographic survey. Groundwater interchange is not yet known, but net groundwater movement is assumed to be negligible for the water balance. Also shown in Table 13 is a water balance for April to October 1980, based on field measurements as well as models. The 4340 dam^3* of outflow unaccounted for may be enhanced evaporation from the Wabamun plant cooling water plume.

Table 12.Water Quality Comparison of Wabamun, Pigeon and Cooking Lakes (adapted from Masuda 1972).

Parameter, mg/L (mean)

Lake	pH	Total Alkalinity	Total Hardness	Nitrate & Nitrite	Phosphate	Sulfate	Chlocide	Conductivity	BOD	Turbidity, JTU	Iron
Wabamun	8.5	183	116	L .1	.02	19.2	2.7	338.3	1.8	1.5	L .1
Pigeon	8.6	153	129	L .1	.1	5	1.1	267	2.1	2.2	L .1
Cooking	8.7	531	308	L .1	1.1	588	21.7	2071	10.1	21.5	.3

Table 13. Morphometric and hydrologic parameters, Wabamun Lake* from Mitchell et al. 1981)

Surface Drainage Area (km^2)	262.8
Lake Surface Area (km^2)	77.7
Total Drainage Area (km^2)	340.5
Lake Volume (m^3)	503×10^6
Mean Depth, m	6.5
Maxium Depth, m	11

Long term average annual conditions, calculated

Surface inflow (dam^3)	14,925
Precipitation to lake (dam^3)	41,408
Lake evaporation (dam^3)	51,867
Surface outflow (dam^3)	4,466
Hydraulic residence time (years)	8.9

April-October 1980, measured

stream inflow (dam^3)	16,789
precipitation to lake (dam^3)	38,416
evaporation (dam^3)	48,562
measured outflow (dam^3)	2,303
residence time (years)	7.7
outflow unaccounted for (dam^3)	4,340
net change in lake level April-October	0

*Based on 1980 hydrographic survey of lake. Residence time estimates neglect groundwater flow.

Earlier water balances for Lake Wabamun concentrated on this enhanced evaporation. Reid, Crowther (1973) estimated a water balance for various degress of thermal input (Table 14) to demonstrate that the lake is in an evaporative regime intensified by the thermal discharge. They estimated that operation of the Wabamun and Sundance (2 units) plants enhanced annual evaporation by 3.09 cm or 2600 dam^3. The lack of a general lake level decline they attributed to groundwater recharge.

Nursall et al. (1972) estimated that surface inflow to the lake (runoff plus precipitation) was 55.1 cm, 3.1. cm greater than the natural evaporation he estimated as 52.0 cm. He feared that even a small increase in evaporation would overcome the excess inflow, having serious effects on lake level.

Table 14. A long-term average water balance for Lake Wabamun, with various degrees of thermal input, assuming only surface discharge to the lake. (Adopted from Reid, Crother 1973 and IEC 1979.)

	THERMAL INPUT			
	None	Wabamun Sundance[1] (pre 1956)	Wabamun Sundance[2] (1972)	Wabamun Sundance[3]
	dam^3/yr			
Natural net evaporation (less precipitation)	20,000	20,000	20,000	20,000
Power plant evaporation	0	2,600	3,400	5,500
Consumptive loss	0	350	450	500
Wabamun Creek	1,850	1,850	1,850	1,850
Total Outflow	21,850	24,800	25,700	27,850
Runoff to lake	12,300	12,300	12,300	12,300
Net annual loss	9,550	12,500	13,400	15,550

All figures were originally given in acre-feet and have been modified to cubic decameters (dam^3).

Ac.ft. X 1.2335 = dam^3 = $1000m^3$

1. Wabamun: 4 units; Sundance: 1 unit
2. Wabamun: 4 units; Sundance: 2 units
3. Wabamun: 4 units; Sundance: 4 units

Sauleslija (1976), using a mass-transfer equation with a wind and stability dependent coefficient, estimated enhanced evaporation from two plants operatin at a capacity of 900 MW would be 2 cm annually. He pointed out that this enhanced evaporation is less than the mean annual discharge of Wabamun Creek (6 cm) which is presumably surplus. Hage (1978) estimated natural evaporation as 54.6 cm. Assuming an average electric load of 400 MW, he estimated enhanced evaporation as 5.5 ± 3.9 cm (or 4675 dam^3) per year. Mitchell et al.'s (1981) volume of 4340 dam^3 of unaccounted outflow is similar to Hage's estimate of enhanced evaporation.

Groundwater may play an important role in the lake's water balance,recharging the lake and preventing lake level declines due to enhanced evaporation (Nursall et al. 1972, Fritz and Krouse 1973, Reid, Crowther 1973).

Fritz and Krouse (1973) and Nursall et al. (1972) used isotoypes of hydrogen (deuterium) and oxygen (O^{18}) in and around the lake to demonstrate an evaporative regime (Figure 12). These isotopes are in higher concentration in the lake water than in either the groundwater or precipitation. The isotope molecules are heavier than normal H_2O^{16} and evaporate more slowly, resulting in gradual enrichment of O^{18} and deuterium. Analysis of fossils Mollusca from alke bottom cores showed similar isotope enrichment indicating that Lake Wabamun has been under an evaporative regime for most of its history. An O^{18} maximum was observed which probably correlates with climatic maximum of about 5000 years ago. Fritz and Krouse (1973) also noted an increase of O^{18} at the top of the samples which presumably occurred in very

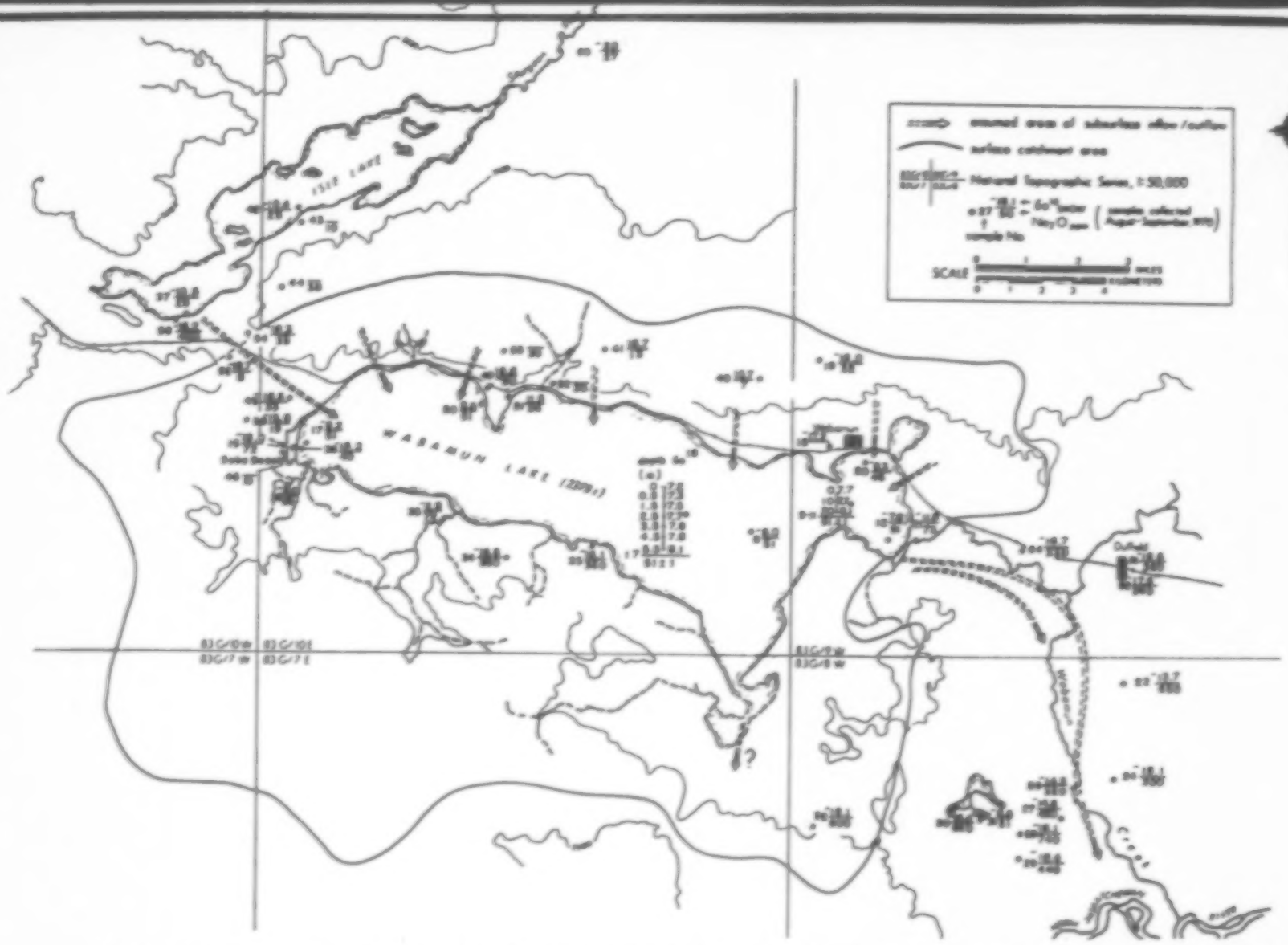

FIGURE 12. ISOTOPE AND CHEMICAL DATA FOR LAKE WABAMUN, LAKE ISLE AND SURROUNDING AQUIFERS. (till samples were collected during aug.- sept. 1970.) (from Nurnell et al - 1972, Fritz and Krouse 1973)

recent lake history; they believed that this indicated increased evaporation after the Wabamun generating plant started operation. However, this suggestion is questionable since other sediment cores show a well mixed surface layer 6 to 16 cm thick and dating from 1958 to 1973 (Reynoldson, pers. comm.).

If one assumes that the lake level is controlled by a balance between surface recharge and evaporation, a relatively high salt content would be expected in an evaporative type of lake such as Wabamun. However, Fritz and Krouse (1973) and Nursall (1972) et al. found a low total dissolved solids level (200 to 300 ppm) and a low sodium content (51 ppm), which seems to contradict the conclusion about evaporation. The low salt values indicate that considerable subsurface flushing must occur.

Other observations made by Fritz and Krouse (1973) and Nursall (1972) et al. which support the theory of groundwater flow-through are:

1) A slight decrease in isotope concentration over the winter, when little precipitation was added to the lake, suggesting subsurface inflow of isotopically lighter water.

2) A lake level rise of 50.8 cm observed between November 1970 and July 1971 which exceeded the calculated runoff.

3) Evaporitic bodies not subject to groundwater flushing reach much higher O^{18} concentrations.

Lake Wabamun appears to be maintained by subsurface flow through aquifers, probably from north to southeast. Fritz and Krouse (1973) suggested that the preglacial valley postulated by Carlson (1971)

functioned as a discharge aquifer, as illustrated in Figure 12. Although the existence of the preglacial channel is questionable (Groundwater Branch 1980), chemical analyses of groundwater support the suggested direction of flow. The sodium content of well water north and west of the lake was found to be low (6 to 40 ppm) while wells south and southeast of the lake had a much higher sodium content (50 to 800 ppm). Wells southeast of the lake also showed a higher than normal O^{18} content (Fritz and Krouse 1973, Nursall et al. 1972). Fritz and Krouse suggested that the monthly amount of subsurface inflow was in the order of 2.5 to 10.2 cm.

Schwartz and Gallup (1978) examined the major ion chemistry of Lake Wabamun (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, SO_4^{2-}, Cl^{-}) in an attempt to determine which factors exerted major control on the lake's water chemistry. They sampled and analyzed water taken from the following components of the hydrologic cycle: the lake, runoff, coal beds, the Paskapoo Formation north and south of the lake, glacial till, the Edmonton Group, and snow. Qualitative comparison of the data showed that the lake most closely resembled the groundwater chemically. The ion chemistry of the lake was nearly identical to that of water from the coal unit. The ion composition of the runoff water and precipitation (snow) was very different from that of the lake water. Schwartz and Gallup's work illustrates the importance of groundwater, especially from the coal unit, to the water balance of the lake.

G. NUTRIENT BUDGET

Reid, Crowther (1973) were the first to propose a nutrient budget for Lake Wabamun. The inventory of input, output and storage sources used in the budget, classified as major or minor items, is shown in the following table.

Table 15. Nutrient Budget Inventory, from Reid, Crowther (1973).

	MAJOR ITEMS	MINOR ITEMS
INPUT	Surface Runoff	Boating
	Wabamun village	Waterfowl
	Cottages	Rainfall
	Drainage from Trans Alta Power Plants	Flyash
STORAGE	Lake water	Algae
	Macrophytes	
	Sediments	
OUTPUT	Macrophyte Harvest	Fish Harvest
		Lake Outflow
		Evaporation

NOTE: Any underground flow is assumed to have equal nutrient content in the inflow and outflow.

Minor items were considered insignificant to the overall budget and were ignored in calculation. Total nitrogen and total phosphorus were calculated for the major items of the budget as shown in Table 16. Data used and assumptions made by Reid, Crowther for their nutrient budget are described in their report (1973).

Nursall (1973) criticized Reid, Crowther's nutrient budget as over-simplistic and for considering rainfall, flyash, algae and fish harvest as minor items of the inventory. Nursall ranked rainfall as the second most important nutrient input source (after surface runoff) and

he estimated that precipitation over the entire drainage system contributed about 10% of the total lake water volume annually.

In Reid, Crowther's estimated budget, surface runoff makes up the majority of the nitrogen and phosphorus input, 90% and 80% respectively. Pointing out the large amounts of nutrient in storage, they suggested that this nutrient reservoir could make any attempted nutrient reduction methods ineffective. They speculated that the lake's nutrient budget has changed little throughout the lake's history.

Reid, Crowther's budget, as stressed by the authors, was qualitative and intended to demonstrate an order of magnitude rather than definite values. Nutrient values for some items were based on inferences from the literature rather than actual measurements in Lake Wabamun.

A quantitative nutrient budget is being developed by Alberta Environment's Lake Wabamun Eutrophication Study (Mitchell et al. 1981). This study has concentrated on phosphorus, which, as in most lakes, appears to be the limiting nutrient in Lake Wabamun throughout the summer and is the nutrient of primary concern in eutrophication control because it may be possible to control its input. Mitchell et al. (1981) reported that major phosphorus sources were surface runoff, ash lagoon effluent precipitation and sediment recycling. Sewage probably makes only a minor contribution, and groundwater is yet unquantified.

Of thirty streams measured during the first year of the three-year study, ten contributed over 90% of the measured phosphorus load in streams. The flyash lagoon effluent stream with its continuous

and relatively large flow was the single largest contributor of water and nutrient (Mitchell et al. 1981).

Table 16. Lake Wabamun Nutrient Budget from Reid, Crowther (1973).

ITEM	TOTAL N (tons/Year)	TOTAL P (tons/Year)
INPUT		
Wabamun Village, Cottages	1	3.4
Trans Alta Drainage	8	0.1
Surface Runoff	100	20
OUTPUT		
Weed Harvest	17	2.5
NET INPUT	92	2.5
STORAGE		
Weeds	70	10
Lake	250	25
Sediments	2000	300

Precipitation and dustfall contributed about 30% to the over-all measured total phosphorus load to the lake during the open water season (Mitchell et al. 1981).

Sediments appear to play a major and dynamic role in nutrient loading to the lake. They contain significant quantities of biologically available phosphorus (BAP), as indicated by algal assays. Seasonal analysis of BAP in sediments suggests release to the water column. Preliminary results of sedimentation-rate experiments indicate resuspension of bottom sediments, with wind-mixing causing flocculent bottom material to re-suspend even in the deepest area of the lake. Sediment core results show mixing to depths of up to 16 cm and suggest an increased sedimentation rate since the 1920 to 1930 period, but no major changes in phosphorus input (Hamilton and Reynoldson 1981, Mitchell et al. 1981).

VI. LAKE BIOTA

A. PHYTOPLANKTON

Wheelock (1969) made the first study of phytoplankton ecology and thermal effluent effect at Lake Wabamun. He characterized the lake as mesotrophic-eutrophic based on phytoplankton species and abundance, and noted the lack of summer blue-green algal blooms. Wheelock concluded that the thermal effluent had no effect on algal species composition; the major effect he observed was that the summer phytoplankton standing crop in the heated area was reduced due to shading from the abundant submerged vascular plants.

Nursall and Gallup (1971) found that the heated effluent indirectly increased the wintertime phytoplankton productivity by maintaining an ice-free area where algae could grow. Like Wheelock, they observed that competition from submerged macrophytes reduced the summertime algal production. They also noted that planktonic algae were disturbed by strong currents in the outlet canal. The phytoplankton species found by Nursall and Gallup (1971) are listed in Table 17.

Noton (1973, 1974, 1975) found that annual net daytime phytoplankton production in the lake as a whole was increased approximately 2% by the heated water from the Wabamun and Sundance plants. The increase was due mainly to wintertime production in the ice-free thermal effluent areas; there was no production under ice cover. Noton did not investigate respiration; whether production is stimulated on a 24 hr. basis depends on the extent to which the thermal effluent affects respiration. Production and assimilation were

Table 17. Phytoplankton species found in Lake Wabamun

(From Gallup and Hickman 1975)

orophyta

Chlamydomonas globosa Snow
Pandorina morum (Mull.) Bory.
Asterococcus limneticus G.M. Smith
Sphaerocystis schroeteri Chodat.
Ankistrodesmus concolutus Corda.
A. falcatus (Corda.)
Cerasterias irregularis G.M. Smith
Chlorella vulgaris Beyer
Closteriopsis longissima Lemm.
Coelastrum cambricum Archer
C. microsporum Naegeli
Crucigenia quadrata Morren
Dictyosphaerium pulchellum Wood
Glococystopsis limneticus G.M. Smith
Kirchneriella contorta (Schmid.) Bohlin
Lagerheimia droescheri (Lemm.) Printz.
Nephrocytium agardhianum Naegeli
Oocystidium ovale Korsch
Oocystis parva West and West
O. pusilla Hansgirg
Pediastrum boryanum (Turp.) Meneghini
P. duplex Meyen
P. duplex var. *clathratum* (A. Braum) Lager.
P. kawraiskyi Schmid.
P. simplex (Meyen) Lemm.
Quadrigula lacustris (Chod.) G.M. Smith
Scenedesmus balatonicus Holt.
S. Bijuga var. *alternans* (Reinsch.) Hansgirg
S. quadricauda (Turp.) Breb.
S. quadricauda var. *longispina* Uherk
S. quadricauda var. *westii* G.M. Smith
Selenastrum bibraianum Reisch
Tetraedron caudatum(Corda.) Hansgirg
T. limneticum Borge
T. minimum (A. Braum) Hansgirg
T. regulare Kutz.
Closterium acutum (Lyngb.) Breb.
C. gracile var. *elongatum* W.& G.S.West
C. lunula Reisch.
Cosmarium sexangulare Lundell
Staurastrum anatinum Cook & Wills
S. chaetocerus (Schroed.) G.M. Smith
S. cuspidatum Breb.
S. leptocladium Nordst
S. paradoxum Meyen

Chrysophyta

Dinobryon divergens Imof.
D. sertularia Ehr.
Mallomonas pseudocoronata Prescott

Euglenophyta

Euglena acus Ehr.
Phacus orbicularis Hubner
Trachelomonas volvocina Ehr.

Pyrrophyta

Ceratium hirundinella (O. Mull) Dujardin
Peridinium cinctum (Muell.) Ehr.

Cyanophyta

Anabaena circinalis (Kutz.) Rab.
A. felisii (Menegh.) Bornette Flahault
A. flos-aquae (Lynch.) Breb.
A. lemmermannii Righter
Aphanocapsa elachista G.S. West
A. pulchra (Kutz.) Rab.

Table 17 (Continued)

Aphanothece nidulans Richter
Chroococcus limneticus Lenn.
C. limneticus var. *carneus* (Chod.) Lemm.
C. limneticus var. *elegans* G.M. Smith
C. turgidus (Kutz.) Naegeli
Coelosphaerium kuetzingianum Naegeli
C. naegelianum Unger
Gomphosphaeria aponina Kutz.
G. aponina var. *delicatula* Virieux
Lyngbya aestuarii (Mert.) Lieb.
L. limnetica Lemm.
L. mucicola Lemm.
Merismopedia glauca (Ehr.) Naegeli
Microcystis aeruginosa Kutz.
Oscillatoria amoena (Kutz.) Gomont
O. bornetti Zukal
Synechocystis aquatilis Sauvageau

Bacillariophyta

Asterionella formosa Hass.
Cocconeis placentula Ehr.
Cyclotella meneghiniana Kutz.
C. comta (Ehr.) Kutz.
C. parva (W. Smith) Cl.
Diatoma elongatum Agardh.
Fragilaria capucina Desm.
F. crotonensis Kitton
Melosira granulata (Ehr.) Ralfs.
M. ambigua (Grun.)O. Mull.
M. varians Agardh.
Rhizoselenia eriensis H. Smith
Stephanodiscus niagarae Ehr.
Synedra ulna (Nitzsch.) Ehr.
Tabellaria fenestrata (Lyngb.) Kutz.

stimulated most in surface water, corresponding to the surface nature of the discharge. There was no significant difference in phytoplankton species composition, nor in nutrient content of the water, between the heated and unheated areas.

B. PHYTOBENTHOS

1) BENTHIC ALGAE

Hickman (1974) found that the standing crop of epipelic algae (algae that are free-living on submerged sediments) was increased in the thermal effluent area, especially in the Wabamun outlet canal. The increased standing crop was due to blue-green algae (Cyanophyta) of the genus Oscillatoria, especially in October, November and December. Hickman found Oscillatoria only in the thermally-affected areas.

The heated effluent did not affect the epipelic algae directly, since the water temperature at the mud-water interface was only 1 to 3°C warmer than that at the control site from February to May. The stimulatory effect of the effluent was indirect; the ice-free area allowed light penetration to the sediments so that algal production continued throughout the winter.

Hickman (1976) studied diatoms at a shallow (water depth 0.5 m) sandy littoral site unaffected by thermal discharge. Wind induced wave action caused much physical disturbance to the sediments and diatoms; sediment cores also indicated well disturbed sediments in the littoral zone (Hickman 1974). Diatom populations were reduced by storm-caused turbulence. Populations also exhibited a distinct seasonal cycle, similar but of shorter duration than in more temperate lakes, consisting

of a spring peak, a summer decline and then an autumn peak (Hickman 1976). The heated water had little effect on diatoms except within the discharge canal where species diversity was reduced (Hickman 1974).

Hickman (1974) also studied algae living attached to sand grains on the lake bottom in the littoral zone. This flora was composed entirely of small diatom species and was apparently not affected by the thermal discharge. Blue-green algae were not found attached to the sand grains.

2) EPIPHYTIC ALGAE

Epiphytic algae are algae growing attached to submerged surfaces such as stems of emergent vegetation. Thermal effluent effects on the epiphytic community were to change species composition, seasonal cycles and standing crop (Gallup ed. 1971). Epiphytic algae growing on stems of the emergent plant Scirpus validus exhibited an increased standing crop and reduced species diversity in thermal effluent areas (Klarer and Hickman 1975, Klarer, Hickman and Gallup 1973). The main effect of the effluent was to extend the growing season for both algae and its substrate, Scirpus, by keeping an ice-free area. Spring and fall maxima were extended, and a large algal population was maintained through the winter. Winter nutrient levels were high; nutrient ions such as phosphate-phosphorus, nitrate-nitrogen and dissolved silica reached their maximum values during the winter in the ice-free areas. In spring, with the epiphyton maximum following ice break-up, the nutrients declined to ambient concentrations of the non-heated areas.

Klarer and Hickman (1975) noted a decreased number of species and increased predominance of a few species in the warm water areas. The

epiphytic algae also exhibited a fall population shift in the plume area (Klarer, Hickman and Gallup 1973), to a greater predominance of Chlorophyta (green algae) and reduction of diatoms.

C. ZOOPLANKTON

Table 18 lists zooplankton species which have been found in Lake Wabamun. Rotifers dominated the zooplankton community from the time of ice break-up to mid-July, after which crustaceans dominated (Gallup et al. 1975). The temperature tolerance range of rotifers varied with species (Gallup 1971, Horkan 1971). In general, the effect of the warm water on rotifers was to accelerate egg production. Horkan (1971) found that the adult survival tolerance range was broader than the temperature range in which eggs were produced. Of the nine most common species, only three species of egg producers and one species that produced live young were able to reproduce successfully over the observed 29°C range. Horkan concluded that temperatures greater than 22.4°C (2.0°C above the observed maximum normal lake temperature) were detrimental to rotifers.

Crustacean species composition was affected by the thermal effluent but the total biomass was not significantly changed (Gallup 1971). Gallup found that mortality in zooplankton passing through the thermal generators varied considerably with species and life stage.

D. ZOOBENTHOS

The benthic fauna of Lake Wabamun is dominated by members of the Chironomidae (class: Insecta, order: Diptera); in the mud sediments the fauna is characteristic of a moderately eutrophic state (Rasmussen

Table 18. Zooplankton species found in Lake Wabamun
(From Gallup and Hickman 1975.)

Rotifera

Ascomorpha Perty
A. ecaudis
A. minima
A. saltans
Ascomorphella Wiszniewski
A. (= Hertwigia) volvocicola
Asplanchna Gosse
A. priodonta
Brachionus Pallas
B. patulus
Cephalodella Bory De St. Vincent
C. sp.
Chromogaster Lauterborn
C. ovalis
Collotheca Harring
C. pelagica
Colurella Bory De St. Vincent
C. sp.
Conochiloides Hlava
C. exiguus
Conochilus Hlava
C. hippocrepis
C. unicornis
Dipleuchlanis De Beauchamp
D. sp.
Encentrum Ehrenburg
E. sp.
Eothinia Harring and Myers
E. sp.
Epiphanes Ehrenberg
E. sp.
Euchlanis Ehrenberg
E. sp.
Filinia Bory De St. Vincent
F. longiseta
Gastropus Imhof
G. hyptopus
G. stylifer
Kellicottia Ahlstrom
K. longispina
Keratella Bory De St. Vincent
K. cochlearis
K. earlinae
K. hiemalis
Lecane Nitschz
L. luna
Mikrocodides Bergendal
M. chlaena
Monostyla Ehrenberg
M. sp.
Mytilina Bory De St. Vincent
M. sp.
Notholca Gosse
N. acuminata
N. foliacea
Ploesoma Herrick
P. lenticulare
Polyarthra Ehrenberg
P. euryptera
P. remata
P. vulgaris
Scaridium Ehrenberg
S. longicaudum
Sinantherina Bory De St. Vincent
S. sp.
Squatinella Bory De St. Vincent
S. sp.
Synchaeta Ehrenberg
S. pectinata
Testudinella Bory De St. Vincent
T. sp.
Trichocerca Lamarck
T. doxon-ruttäli
T. longiseta
T. multicrinis
T. porcellus
Trichotria Bory De St. Vincent
T. pocillum
T. tetractis
Trochosphaera Semper
T. aequatorialis

Cladocera
Leptodora kindtii (Focke)
Sida crystallina (O.F. Muller)
Daphnia rosea Sars emend. Richard
Daphnia galeata Sars *mendotae* Birge
Daphnia retrocurva Forbes
Simocephalus vetulus Schodler
Simocephalus serrulatus (Koch)
Ceriodaphnia reticulata (Jurine)
Bosmina longirostris (O.F. Muller)
Diaphanosoma leuchtenbergianum Fischer
Eurycercus lamellatus (O.F. Muller)
Alona affinis (Leydig)
Chydorus sphaericus (O.F. Muller)

Table 18 (Continued)

Copepoda
Diaptomus oregonensis Lilljeborg
Cyclops vernalis Fischer
Cyclops bicuspidatus thomasi S.A. Forbes
Eucyclops speratus (Lilljeborg)

1979). The effect of the thermal plume was to alter species composition. Benthic fauna of the thermal discharge area was characteristic of a high degree of eutrophication, dominated by the larger Chironomus spp. larvae. In the immediate vicinity of the discharge canal there was less species diversity and a different community structure than in sites further from the discharge (Gallup, Hickman and Rasmussen 1975, Rasmussen 1979). At the mouth of the discharge canal the benthos was dominated by tubificid oligochaetes, sphaeriid clams and Turbellaria, rather than Chironomus spp. Gammarus lacustris, a cold stenothermic amphipod common in unheated areas of Kapasiwin Bay, was greatly reduced or absent near the discharge canal. Despite the differences in species composition, Gallup et al. (1975) found that the benthic fauna standing crops of heated and unheated sites in Kapasiwin Bay were reasonably comparable. Comparison of the heated area with a more exposed site at Fallis Point showed that the warmer site had a greater density and different species composition of zoobenthos (Gallup et al. 1975). Rasmussen (1979) stated that the amount of decomposing plant material within the sediments appeared to be the main trophic factor affecting the zoobenthic species composition. He attributed the enhanced trophic status of the sediments of the heated bays to the abundant decaying macrophyte remains within the ooze.

Gallup et al. (1975) identified a number of factors which probably caused the observed differences in benthic fauna between a thermal plume site and an unheated site in Kapasiwin Bay. These were: (1) the water temperature -- its direct selective effect and rapid temperature

fluctuations; (2) the outlet canal current; (3) sediment type and (4) modification of the sediments by the animals living in them.

Thermal enrichment increased rates of egg development and growth in the snail Physa gyrina, thus shortening generation time, and allowing continous year-round reproduction (Sankurathri 1974, Sankurathri and Holmes 1976). Thermal effluents permitted year-round transmission of trematode parasites in Physa. The effluent also reduced Chaetogaster sp., an effective biological control agent for the trematode parasites, resulting in higher snail infestations (Sankurathri 1974).

E. FISH

Eight species of fish, listed in Table 19, have been found in Lake Wabamun (Ash 1974). Lake whitefish followed by northern pike are the most important species to both sport and commercial fishing. The lake supports large populations of these species. White suckers, spottail shiners and yellow perch are also numerous. Less common are burbot, brook stickleback, and Iowa darters (Ash 1974).

Table 19. Species of fish collected from Lake Wabamun (from Ash 1974).

COMMON NAME	SPECIES
Lake Whitefish	*Coregonus clupeaformis* (Mitchill)
Northern Pike	*Esox lucius* L.
White Sucker	*Catostomus commersoni* (Lacepede)
Burbot	*Lota lota* (L.)
Yellow Perch	*Perca flavescens* (Mitchill)
Spottail Shiner	*Notropis hudsonius* (Clinton)
Brook Stickleback	*Culaea inconstans* (Kirtland)
Iowa Darter	*Etheostoma exile* (Girard)

Commercial fishing yields indicate that whitefish and pike populations have fluctuated over the years. Some of the earliest scientific reports on Lake Wabamun (Dempsey 1942, Miller 1942, 1943 a,b) dealt with fish production and condition, of concern to the commercial fishery. There have been several periods where over-fishing greatly reduced and stunted populations, forcing closures of the commercial season. Populations have recovered and now both whitefish and pike populations are healthy. Recognizing the increasing popularity of sport fishing, Alberta Fish and Wildlife's management objective is to protect the sport fishery by the allocation of quotas. Over one half of the potential whitefish production is allocated to sport fishing with the remainder divided between the commercial fishery and the Indian domestic

fishery. Lake Wabamun's commercial and sport fisheries are discussed in more detail in Section 3.

Lake whitefish are fall spawners and eggs require low incubation temperatures (optimum is 0.5°C , maximum limit is 6°C [Price 1940, cited by Beak 1980]) over the winter for successful hatching. Ash (1974, 1975) studied the effects of the thermal effluent on the whitefish and their egg survival. There were certain physiological indications that whitefish in the heated areas may have spawned earlier, although this was not proven. Any factor causing fish to spawn earlier than normal would be detrimental since egg incubation at elevated temperature would cause greater egg mortality and embryo abnormality, and earlier hatching (Ash 1974).

Prime whitefish spawning substrate is rock and sand, of which about 70% is found in the east end of the lake. Much of this area was influenced by a warm water current from the Sundance plant (Ash 1974). The warm water apparently stimulated some whitefish to spawn in an ooze substrate in the plume area; eggs were not found in similar substrate in cold water areas of the lake (Ash 1974, 1975). Eggs incubated in the heated area had very poor survival due to a combination of factors: increased water temperature, unsuitable substrate, siltation and greater fungal growth due to high temperatures. These eggs also showed faster development and earlier hatching (Ash 1974, 1975).

The condition factor of the whitefish from the warm water area was generally higher than that of fish from elsewhere in the lake, and it was consistently greater for females in the heated area. However the

thermal effluent did not seem to affect length-weight relationships or fecundity (Ash 1974).

The diet of fish in the warm water areas was quite different from those in the rest of the lake. Whitefish in the unheated areas consumed planktonic organisms, macrobenthos and small perch. Elodea shoots were the major dietary item for the fish in the warm water area. They also fed more on gastropods.

In February 1973 a mechanical failure at the Sundance plant caused temporary cessation of cooling water discharge resulting in a 16.9° water temperature drop within 30 min. in the discharge canal. The drastic temperature change caused a fish kill due to "cold shock", which was documented by Ash et al. (1974). Most of the dead fish counted were shiners; no dead whitefish were seen.

Gallup et al. (1973), in tests of weed harvesting and herbiciding, found that weed cutting reduced the numbers of the snail Physa gyrina. They speculated that these activities would have little effect on food availability to whitefish, since whitefish prefer snails of the Valvata genus. Valvata spp. actually increased following weed harvesting. However any significant reduction of chironomids by herbiciding over a large area could have drastic effects upon available food, since chironomids are an important item in the whitefish summer diet.

Other fish species, however, could be adversely affected by the removal of aquatic macrophytes. Gallup et al. (1973) found small fish of pike, perch, burbot, shiners and stickleback within the cut weeds.

Pike spawn in the spring in the shallow water of inlet streams and marshy areas using submerged aquatic vegetation and flooded terrestrial

vegetation as a substrate. The young hatch in 14 to 21 days and for the first few days cling to vegetation. They leave the spawning grounds for deeper water after about one month (Beak 1975). Gallup et al. (1973) recommended that weed harvesting should not commence until mid-June to ensure that pike fry attached to the macrophytes would not be harmed.

Despite concerns that a significant pike spawning ground might be affected by the incorporation of upper Goosequill Bay into the 480 ha Sundance cooling pond, the loss of upper Goosequill Bay, used by an estimated 6.5 to 10.3% of the pike population for spawning, apparently had no immediate deterimental impact on the pike population. There were no indications of overcrowding or population reduction (Beak 1975, 1976).

A winter fish kill in Goosequill Bay in January 1974 may have resulted from a combination of low dissolved oxygen, high pH and/or toxic effluent (Reynoldson 1974). The bay is connected to the lake only by a canal beneath the railway tressle and receives Sundance ash lagoon effluent. Reynoldson found dissolved oxygen and pH were 0 ppm and 9.7 respectively in the bay and 10.4 ppm and 8.2 respectively in the lake.

VII. AQUATIC MACROPHYTES

A. BACKGROUND

Aquatic macrophytes are a natural and essential part of lake communities, providing food and habitat to invertebrates, fish and waterfowl, but they become a nuisance when they interfere with human activities. Most of Alberta's lakes are mesotrophic to eutrophic and support heavy macrophyte growths (Reynoldson 1977). With the increasing recreational use of the province's lakes there is inevitably conflict between natural conditions and human desires, resulting in the perception of a "weed problem" in many lakes.

Aquatic macrophytes have probably been abundant in Lake Wabamun long before settlement. They were a nuisance to early cottagers who had to clear weeds from their beaches. In recent years lake users have consistently identified aquatic macrophytes as a major problem at Lake Wabamun. Weeds degrade the quality of recreation by tangling on motorboat propellers, snagging fishing lines, impeding swimmers and water skiers, and washing onto beaches and decomposing.

A list of Lake Wabamun's aquatic macrophyte species is found in Table 20. The most frequently occurring species are, in order, Chara globularis, Myriophyllum exalbescens, and Potamogeton richardsonii (Haag and Gorham 1979). Other Potamogeton spp. are common as well.

The first scientific documentation of macrophytes in Lake Wabamun was by Dobson and Stanley (1961), who noted four species associated with the Wabamun thermal discharge, Potamogeton pectinatus, P. zosteriformis, P. sp. (unidentifed) and Ceratophyllum demersum. Otherwise they found plant growth was affected only slightly by the thermal discharge. Exposure and water depth determined zonation of

Table 20. Aquatic macrophyte species in Lake Wabamun (From Beak 1980).

Scientific Name	Common Name
Chara globularis	
Typha latifolia	Common Cattail
Najas flexilis (Willd.) Rostk. & Schmidt	
Potamogeton filiformis Pers.	
P. friesii Rupr.	
P. gramineus L.	
P. natans L.	
P. pectinatus L.	Sago Pondweed
P. praelongus Wulf.	White-stem Pondweed
P. pusillus L.	
P. richardsonii (Benn.) Rybd.	Clasping-leaf Pondweed
P. vaginatus Trucz.	Large-sheath Pondweed
P. zosteriformis Fern.	Flat-stemmed Pondweed
Zannichellia palustris L.	Horned Pondweed
Alisma plantago-aquatica L.	Broad-leaved Water-plantain
Sagittaria cuneata Sheld.	Arrowhead
Elodea canadensis Michx.	Canada Waterweed
Scirpus sp.	Bulrush
Lemna minor L.	Common Duckweed
L. trisulca L.	
Polygonum coccineum Muhl.	Water Smartweed
Nuphar variegatum Engelm.	Yellow Pond-lily
Ceratophyllum demersum L.	Hornwort
Ranunculus circinatus Sibth.	White Water Crowfoot
Myriophyllum exalbescens Fern.	Water Milfoil
Hippurus vulgaris L.	Mare's-tail
Utricularia L.	Common Bladderwort

plants; 4.27 m was the maximum depth for rooted plants (Dobson and Stanley 1961).

The Wabamun power plant in 1956 began discharging hot water in Kapasiwin Bay, a shallow bay that already supported dense macrophyte growths. In the early 1960's lake levels dropped, promoting macrophyte growth. From 1956 to 1967 the volume of the Wabamun discharge increased as generating units were added to the plant. The Sundance plant began operation in 1970 and doubled its capacity in 1973.

By the early 1970's it was evident that the pattern of weed growth had changed significantly. In Kapasiwin Bay there seemed to be more growth and there was a definite species change from a Myriophyllum - Chara community to one dominated by Elodea canadensis (Allen and Gorham 1973). An Elodea bed also developed near the Sundance discharge, and beds appeared at Seba Beach, Gardner's Cove and Moonlight Bay (Beak 1980).

Many cottagers blamed accelerated weed growth on the thermal effluent (ERCB 1972) and as a result of complaints much scientific attention has been focused on the relationship between thermal discharge and weed growth. Much of the scientific attention centered on Elodea canadensis, a plant considered uncommon to rare in Alberta. Not recorded by Dobson and Stanley (1961) it was first documented in Lake Wabamun in 1968 (Wheelock 1969). Several years later it had become the most dominant and troublesome plant in the east end of the lake (Allen and Gorham 1973). Reid, Crowther (1973) concluded that Elodea's dramatic increase was primarily due to the thermal discharge. However by the mid-1970's Elodea populations declined significantly; it is now no longer considered a nuisance (Beak 1980).

B. AQUATIC MACROPHYTE DISTRIBUTION

The distribution of submerged rooted plants is limited by light penetration, turbulence and nutrient availability. The photic zone, where enough light is available for photosynthesis, is defined as the depth receiving 1% or more of surface irradiance intensity (Ruttner 1963). In Lake Wabamun it varies between 4.5 and 5.5 m (Haag and Gorham 1979). Potential macrophyte habitat, as defined by the 5 m depth contour, comprises 31% of the total lake area and is a narraw band around most of the lake except for Kapasiwin and Indian Bays (Haag and Gorham 1979).

Within the photic zone, wind and wave action are the major direct and indirect factors governing plant cover and species distribution. Turbulence, which is related to both exposure and depth, affects plants directly by pulling and tearing, and indirectly by determining substrate type and particle size. Fine-textured sediments occur with deeper water or less turbulence and have a higher nutrient content than coarse textured sediments (Haag and Gorham 1979).

Haag and Gorham (1979) identified two distinct habitat types based on exposure and sediment texture. Exposed habitats, with rock to sand bottoms, predominate on the north and south shores and in the eastern portions of Kapasiwin and Indian Bays and generally lack emergent plants. Chara is usually the dominant submerged macrophyte species. Sheltered habitats having finer textured sediments with a lower sand content generally support greater total plant cover and greater species diversity than exposed habitats. They tend to be dominated by Myriophyllum and Potamogeton richardsonii. The tolerance range for sediment texture is very variable between the different species. Chara,

Myriophyllum, P. vaginatus and P. richardsonii occupy the broadest range of sediment texture.

Haag and Gorham (1979) also found that a high degree of local instability and high turnover rate appears to be a normal condition of the Lake Wabamun aquatic macrophyte community structure. They found that species composition and percentage cover varied greatly from year to year; they recorded numerous cases of both local establishments and extinctions. Extinction frequencies were more than 25% for all the common species except Chara. Establishment probability was more variable. The high turnover rate is due to uprooting of plants and dispersal of vegetative propagules by turbulence.

C. ELODEA

Although indigenous to North America, Elodea canadensis is rarely found in Alberta because of the severity of the climate. Its success and the resultant problems in Lake Wabamun made it the subject of much study.

Newly established Elodea exhibits a typical growth pattern, usually spanning 20 to 25 years. It initially thrives with the population expanding to become a nuisance for a few years and then abruptly declines in abundance and ceases to be troublesome. This pattern has been well documented in Britain and Europe (references listed in Beak 1980). Areas once infested with abundant Elodea have not experienced a recurrence of the problem, even within 100 years (Beak 1980)

Elodea canadensis (Fig.13) is a frail plant that grows completely submerged, supported by the surrounding water. The long fragile

segmented stem is produced from an apical meristem that over-winters in the form of dense winter buds.

Although Elodea does produce flowers, sexual reproduction plays no part in the life cycle. Commonly only one sex, usually female, is represented in a population, but in Lake Wabamun only male flowers have been found. Elodea's success and spread is due entirely to vegetative reproduction. Any stem fragment containing a lateral bud, which occur in the axils of every sixth to eighth internode, is capable of producing a new plant. Winter buds, which may be released and dispersed at any time during the winter, also make good propagules. In Lake Wabamun the most dramatic spread of Elodea was by large drifting rafts of plants, which would settle over an area, smothering competing plant species. Rafts, or mats of broken off plants, are produced in the summer. If rafting occurs early enough a second crop may be produced by either the parent population or the newly established colony (Beak 1980).

D. SPECIES CHANGES

Allen and Gorham (1973) observed aquatic plant community changes between 1969 to 1973. They speculated that at the Wabamun outlet, the installation of the fourth and largest generating unit resulted in the local Chara community being killed by the additional heat and silt load, and invasion of the resulting "hole" by Elodea. Direct observations of the species changes associated with the commissioning of the Sundance plant in late 1970 supported these speculations. In Goosequill Bay the original Chara-Myriophylum-Potamogeton community died out under siltation conditions and Elodea invaded and spread. Elodea distribution roughly coincided with the zones most affected by the thermal discharge

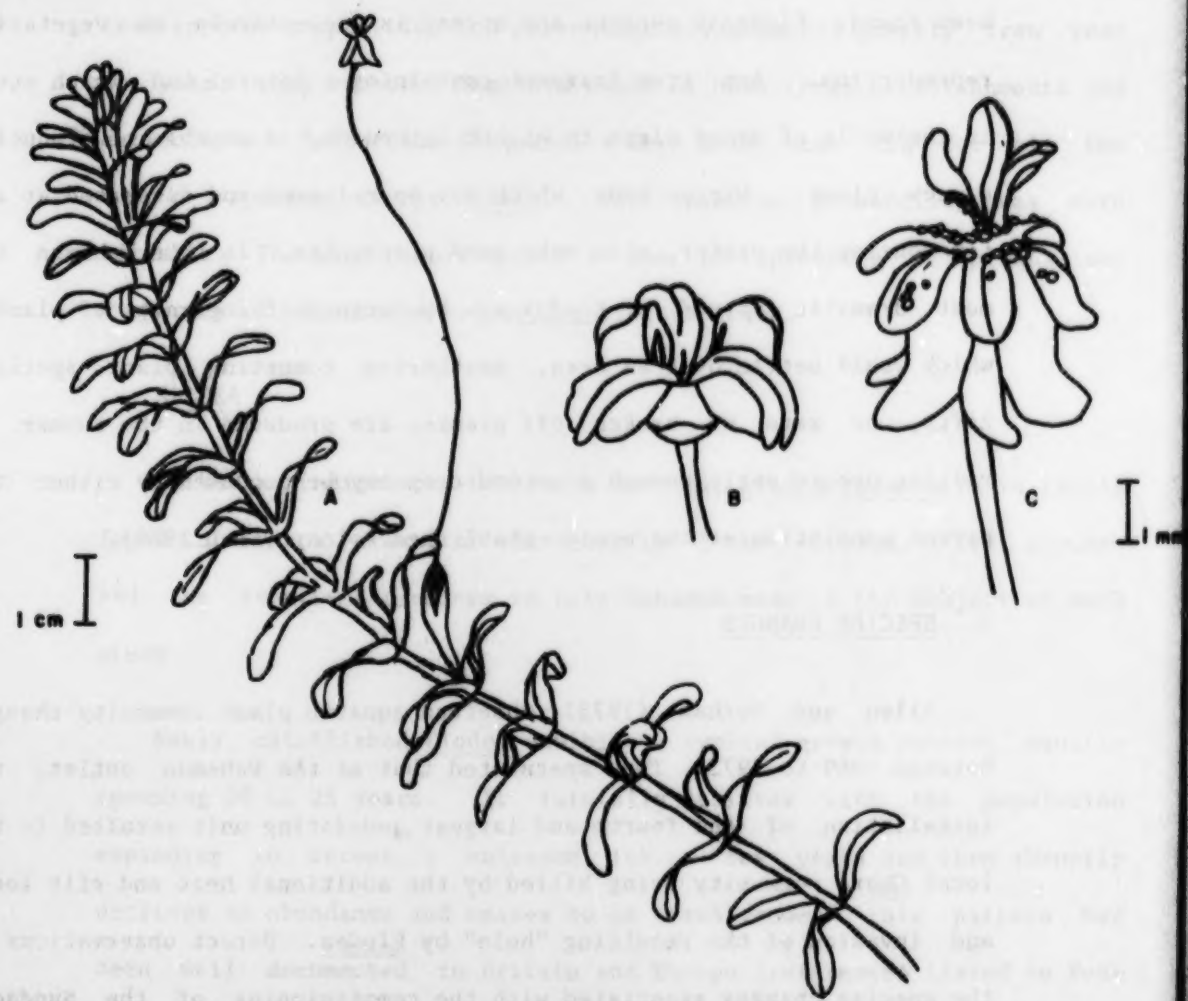

FIGURE 13. ELODEA CANADENSIS RICH: A) HABIT, B) MALE FLOWER C) FEMALE FLOWER. (from Cook 1974.)

(Allen 1973). P. pectinatus, a species adapted to swiftly-flowing currents, colonized the discharge canal area. Kapasiwin Bay weed growth fluctuations, which Allen and Gorham estimated from annual air photos, correlated more with lake water levels and hours of sunshine than with thermal effluent. They concluded that the lake's weed problem "...is not so much one of increased quantities being produced as a consequence of the operation of the two power plants (although we cannot be sure that this may not be occurring to some extent), it is rather the change of species which has greatly aggravated an already bad situation" (Allen and Gorham 1973).

E. DORMANCY STUDIES

Haag (1979) used the unusual (i.e., thermally enriched) situation in Lake Wabamun to examine the ecological significance of dormancy in rooted aquatic plants. He compared Elodea with two other common species in Lake Wabamun and found that Elodea lacks true dormancy and is capable of growth at any time of the year. Myriophyluum exalbescens exhibits weak dormancy, easily broken by temperatures of 10°C, while Potamogeton zosteriformis shows strong dormancy. Elodea's lack of dormancy makes its survival strongly dependent on winter irradiance, which is greatly attenuated by ice and snow cover.

Elodea's success in Lake Wabamun has been attributed to the lack of ice cover, and hence more winter irradiance in the thermal effluent zone, rather than to the warm water itself (Allen 1973, Haag 1977, 1979, Haag and Gorham 1977, 1979). There is strong thermal stratification of the plume with low (2°C) temperatures occurring near the bottom (Haag and Gorham 1977). Because of its lack of dormancy, Elodea is able to overwinter as growing plants, if winter light is adequate. The thermal

discharge creates this condition by maintaining the open-water zone. In the normal winter condition of ice and snow cover, almost no light penetrates and the standing crop of dormant plants, stem fragments and rhizomes is very low (Haag and Gorham 1979). Despite the lack of ice cover in the effluent zone, the native species still become dormant in the winter and have to break dormancy in the spring. Elodea, because it has been slowly growing all winter in the ice-free area, has a head-start and matures earlier than the native species (Allen 1973).

A much greater winter standing crop of aquatic plants, dominated by Elodea, existed in the effluent zone than under ice cover. Elodea dominated spring growth; after spring turnover Elodea growth was greater within the thermal zone than beyond it (Haag and Gorham 1977).

Elodea in the thermal discharge area was phenologically different from Elodea in far-field areas (Allen 1973, Haag and Gorham 1977, Beak 1980). In the thermal discharge area stem elongation was initiated up to two months earlier, flowers were produced earlier and more abundantly, senescence and rafting occurred earlier, making dispersal more successful. Early senescing parent populations had time to grow a second crop.

In laboratory conditions of controlled light and temperature, Allen (1973) found that of four major species in Lake Wabamun (Elodea, Myriophyllum exalbescens, Potamogeton pectinatus and Chara), Elodea had the most efficient net carbon assimilation under all conditions tested (light intensity up to 260 $mE/m^2/s$; temperature 5° to 25°C). Elodea proved to be particularly efficient at low light levels and its assimilation rose rapidly as light intensity increased. Thus Elodea can assimilate carbon better than its competitors at great depths, on cloudy

days and over a wider temperature range, especially at higher temperatures (Allen-1973).

Haag (1977) described the ecological strategy of Elodea's life cycle as an attempt at earlier establishment, growth and reproduction. This strategy generally fails in Alberta's climate, but it pre-adapts the plant to a thermal effluent. Haag and Gorham (1977) doubted that Elodea would spread to the rest of the lake, since its lack of dormancy makes it poorly adapted to normal winter conditions.

F. BEAK CONSULTANTS' WEED REPORT

Beak Consultants Ltd., contracted by TransAlta to determine the relationship between the thermal effluent and aquatic weed growth, directed most of their attention to Elodea which at the time was the major nuisance weed. They attempted to explain the "boom and bust" Elodea pattern that they documented at a number of locations in the lake, and to predict if and where Elodea might outbreak again. The Elodea populations showed a similar pattern of colonization, abundance for several years, followed by a crash. All populations crashed between 1975 and 1977 except for that at the Wabamun outlet which remains abundant in a 10 ha area. Following the cessation of the Sundance thermal discharge in December 1975, the Sundance outlet Elodea population increased in the summer of 1976 and then practically died out in 1977. Other species changes following the cessation of the discharge included the decline of Myriophyllum and Potamogeton pectinatus in 1977, along with a bloom of filamentous green algae, and increases in P. zosteriformis, P.richardsonii and Chara (Beak 1980).

Beak considered a number of hypotheses to explain the observed patterns. The Sundance crash could not be explained by the removal of

light and heat; the effect would have been more immediate. Since Elodea was almost a monoculture there, competition from other species was ruled out. Other hypotheses considered and eliminated were genetic deterioration, disease, and phenological changes. Suspecting depletion of a critical sediment nutrient, Beak undertook sediment chemical analyses and found a high correlation between ferrous iron and Elodea abundance. Sampling stations with abundant Elodea had high levels of both total and ferrous iron in the sediments. Stations where once abundant Elodea had crashed had very low sediment iron levels; 150 mg/g (dry weight) of either total or ferrous iron appeared to be the threshold below which Elodea did not flourish. Iron levels were apparently not critical to other plant species. From this Beak concluded that the crash of Elodea populations was due to the depletion of ferrous iron (the most bio-available form of iron) in the sediments.

Beak also determined other factors which were necessary for successful Elodea growth and propagation. These are:

1) Water depth 1 to 4.5 m
2) Mud substrate
3) Protection from turbulence; and
4) Ice cover nil or of short duration (for successful propagation).

The only large remaining Elodea population at the time of the Beak report was a 10 ha area at the Wabamun outlet where the thermal effluent keeps winter light availability high by maintaining an ice-free area. Small populations also existed at Seba Beach, Moonlight Bay and Sundance. Sediment ferrous iron levels at the Wabamun outlet were high; apparently Elodea had not depleted the iron reserve here. Whether the high iron levels were coincidental or whether the discharge replenishes iron was not determined.

Using the criteria for successful Elodea growth and propagation Beak developed a model (Figure 14) to predict areas of potential Elodea growth. They concluded that less than 10% of the lake was suitable for growth (Figure 15) that it would face competition from native species, and that it could spread only as rafts from the Wabamun outlet population which could be intercepted by mechanical harvesting. Therefore, the nuisance situation of the early 1970's was unlikely to recur.

Regarding other native macrophyte species, Beak stated that Kapasiwin Bay probably has always been weedy due to its shallow depth and fine-textured sediments. Other macrophytes are occasionally a nuisance. The discharge has affected species compositon near the outlet, but the abundance, distribution and nuisance level of most species throughout the lake is more likely influenced by depth, sediment texture and turbulence than by thermal discharge (Beak 1980).

With respect to altering or stopping the Wabamun discharge as a means of controlling macrophyte growth, Beak concluded that no manipulation of the discharge would eliminate or substantially reduce the nuisance of weeds in Kapasiwin Bay. in fact the construction activity and associated siltation and disturbance of bottom sediments resulting from building either an open or closed cooling system might actually create ideal new Elodea habitat. This would also be very costly, with capital cost estimates ranging from $7 to $36 million (1977 dollars) and operating costs of up to $1 million per year (MEC 1978). Continued flow of the Wabamun discharge would probably maintain a small area of Elodea but rafts produced by this population could be intercepted by efficient mechanical harvesting. Of the methods of control considered, the most attractive in terms of cost and impacts was

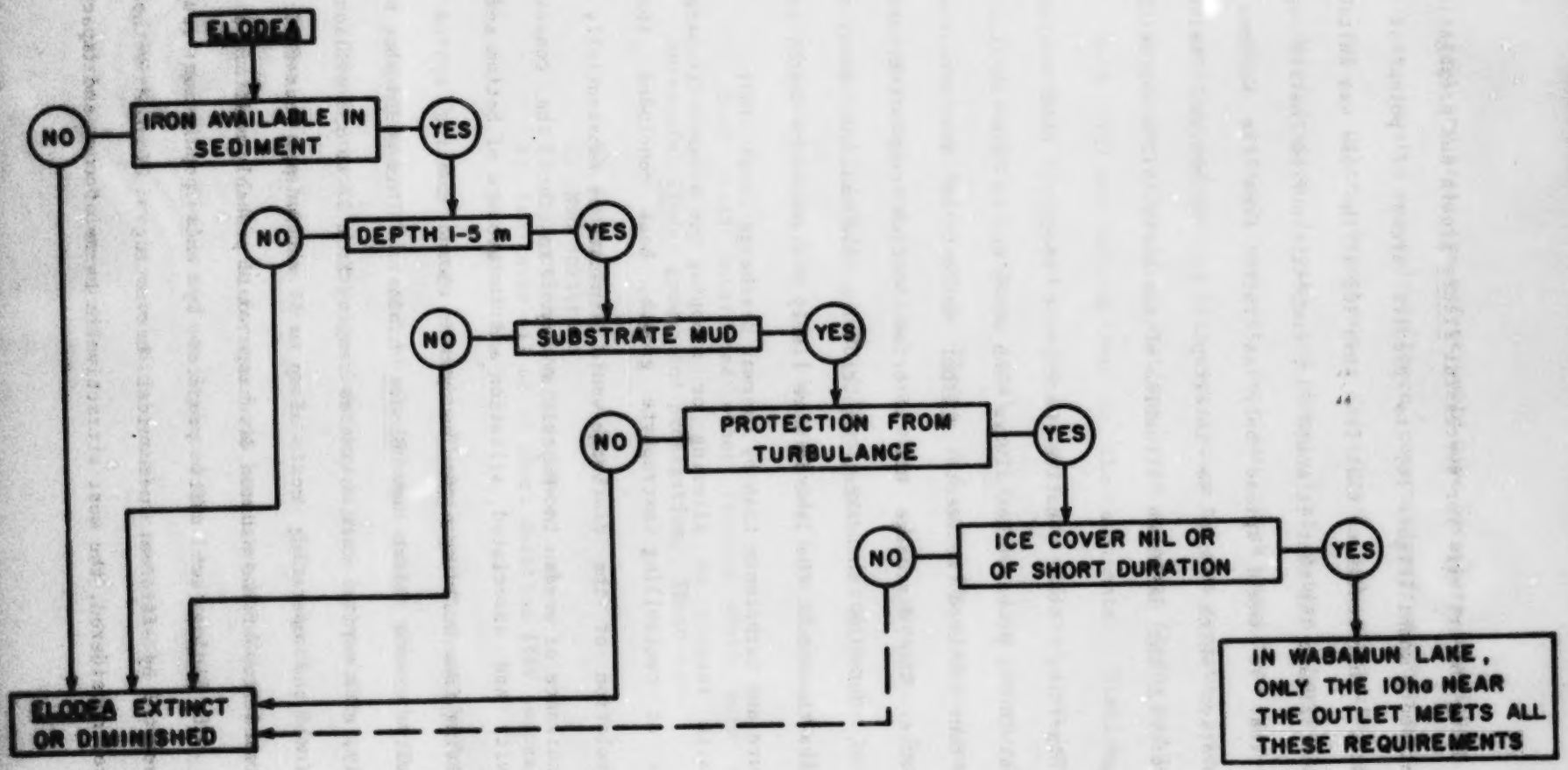

FIGURE 14. FLOW CHART OF ELODEA HABITAT REQUIREMENTS, BASED ON BEAK CONSULTANT'S, LTD. (1980) IRON HYPOTHESIS

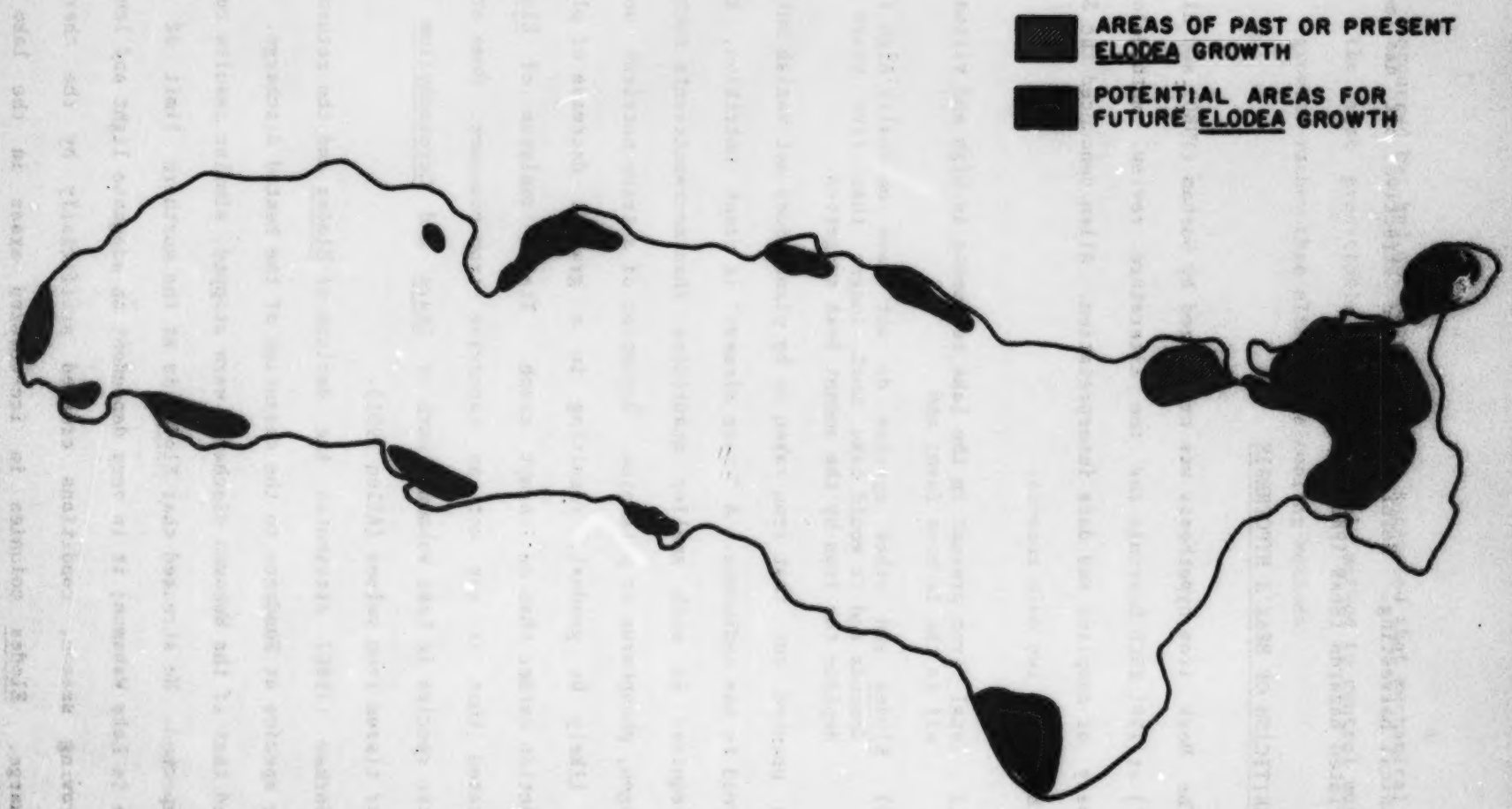

FIGURE 15. AREAS OF POTENTIAL FUTURE ELODEA GROWTH IN LAKE WABAMUN. (from Beak 1960)

mechanical harvesting. Herbiciding can be effective but has more associated hazards (Beak 1980).

G. CRITICISM OF BEAK'S HYPOTHESIS

The Beak iron hypothesis was criticized by Gorham (1980) and Allen (1981) at 1981 ERCB hearings for the literature review, methodology, adequacy of sampling and data interpretation. Allen denounced the Beak hypothesis for two main reasons:

1) Total iron present in the lake sediments is high and virtually all in the ferrous form; and

2) Elodea and other species do not have unusually high iron demands and it would take much longer than five years to deplete the iron by the amount Beak suggested.

Allen pointed out that iron taken up by plants does not vanish but is returned to the sediments. A "trace element" in plant nutrition, iron is required in much smaller quantities than macronutrients such as nitrogen, phosphorus or potassium. Depletion of a trace nutrient would more likely be gradual, resulting in a gradual decrease of plant production rather than an abrupt crash. Tissue analyses of Elodea indicated that it was not an excessive iron consumer. Some other aquatic species in Lake Wabamun, such as Chara and Ceratophyllum had higher tissue iron values (Allen 1981).

Gorham (1980) attributed the decline of Elodea and the return of other species at Sundance to the cessation of the heated discharge. He stated that if the Wabamun discharge were stopped, similar results could be expected. He stressed that Elodea is at the northern limit of its range in Lake Wabamun; it is very dependent on adequate light and length of growing season, conditions created artificially by the thermal discharge. Elodea colonies in ice-covered areas in the lake had

occurred but had not persisted. He suggested that mechanical harvest is the most predictable and economical method to control nuisance weed growths rather than alternative cooling methods.

VIII. CONTROL OF AQUATIC MACROPHYTES

Excessive and increasing aquatic macrophyte growths have constantly been identified by lake users as the major problem at Lake Wabamun. Citizen groups have already urged the government and TransAlta for its control.

Two broad strategies include: (1) control of the symptoms (the plants themselves); and (2) control of the causes of excess growth.

Symptomatic control would include weed harvesting, herbiciding, biological controls such as introduction of herbivores or pathogenic micro-organisms, and habitat manipulation such as shading, dredging, water level manipulation or sand blanketing.

To control the cause it first must be identifed. The thermal discharge appears to be an obvious culprit especially since thermal enrichment can increase productivity (Gallup (ed.) 1971).

The thermal discharge has been identified as the primary cause of a species change to Elodea, mainly by maintaining an ice-free area in the winter where conditions are suitable for Elodea growth (Reid, Crowther 1973, Haag and Gorham 1977, Beak 1980). However the extent and effect of the hot water is limited to a localized area around the Wabamun outlet where it is discharged into a shallow already highly productive bay. The localized effects of a species composition change favoring Elodea canadensis and increased production and growth have not spread to unheated areas of the lake (Haag and Gorham 1977).

Cessation of the heated discharge will not eliminate weed growth in naturally weedy areas. The cessation of the Sundance discharge, which cost approximately $40 million, may have preserved a large whitefish spawning area, but did not eliminate weed growth. Although Elodea

declined, other macrophytes replaced it. Eliminating the Wabamun discharge might result in the elimination of the Elodea population there, but probably would have little effect in reducing the overall abundance of native weeds in the area.

A. OPTIONS FOR CONTROL OF SYMPTOMS

1) MECHANICAL HARVESTING

Mechanical harvesting of weeds during the growing season was initiated by the Alberta Government in 1971 and has been continued annually by TransAlta since 1972. Floating harvesters cut and remove weeds from a 127.9 ha area in Kapasiwin Bay. Weeds are cut at depths from 0.6 m to 1.5 m, and are disposed of in a worked-out gravel pit. A 900 m floating boom to prevent weed rafts from washing up on Kapasiwin Beach is used in conjunction with the harvest program, but was not installed in 1980 at the request of the Summer Village of Kapasiwin, since the boom also reduced beach cleansing wave action.

The total yield declined significantly after 1974. In 1980 the amount of Elodea was down substantially from previous years.

Total cost of the 1980 operation was $53,700. Beak (1980) estimated the average annual cost per hectare to be $420 (1979 Cnd. dollars).

Short term effects of the weed harvesting program were investigated by Gallup et al. (1973, 1975), who found a significant decrease in the snail Physa gyrina (68%) followed by a significant increase in other snails, Valvata spp. and Promenetus exacuous (56%). Chronomids decreased

Table 21 outlines the results of the weed harvesting program.

Table 21. Summary of TransAlta weed harvesting program, 1972-1980 (adapted from Calgary Power 1980).

	YEAR								
	1972	1973	1974	1975	1976	1977	1978	1979	1980
Total weeds removed (tons, wet weight)	1701	5138	2276	348	259	384	707	410	28
Area harvested (acres)	207	281	184	138	75	161	207	143	9
Tons per acre	8.2	18.3	12.4	2.5	3.5	2.4	3.4	2.9	3.

by 15% and amphipods by 54%; other species were little affected. The net effect of the weed cutting was a 12% reduction in invertebrate density. One month after cutting, benthic algae increased slightly but not significantly. They surmised that the weed cutting would have little effect on whitefish feeding; stomach analyses indicated that whitefish preferred Valvata to Physa, although chironomids were also an important dietary item. The whitefish did not appear to avoid the cut areas.

Gallup et al. (1975) found numerous pike fry and other small fish within the cut weeds. The young pike fry cling to the submerged vegetation for five to ten days after hatching. They recommended:

1. Weed harvesting should be confined to open water zones and should never be allowed among the emergent higher plants, in order to maintain habitat for macroinvertebrates, forage fish, spawning pike and pike fry, and waterfowl,
2. Weed cutting should be confined to the upper part of the plant (at least 30 cm, preferably 1 m above the substrate) to preserve fish and invertebrate habitat; and

3. Cutting should not commence until mid-June, to protect pike fry (Gallup et al. 1975).

Nutrient removal by harvesting can be significant (referenced by Beak 1980), although this is probably not the case in Lake Wabamun. Beak (1974) estimated that macrophyte harvesting in 1972 and 1973 removed only 1.72 tons of phosphorus and 11.08 tons of nitrogen (dry weight), amounts comparable to those removed by the commercial fishery, and probably insignificant to the total nutrient budget (Beak 1980).

A disadvantage of weed harvesting is that it must be repeated at least annually. Removal of the cut weeds reduces reinfestation and spread by vegetative propagation.

Two major consultants' reports to TransAlta have recommended mechanical weed harvesting over alternate discharge cooling schemes, both for economical and biological reasons. Beak (1980) stated that consistent mechanical harvesting would provide greater and more predictable control of all macrophyte species than discharge cessation or manipulation.

International Environmental Consultants (1979) recommended expanded weed harvesting with no change in the existing cooling system as the only alternative with significant beneficial impacts, only minor negative impacts and comparatively very minor capital and operating costs. In addition it would have the least economic impact on electric power consumers.

2) HERBICIDE APPLICATION

Herbiciding can be an effective aquatic macrophyte control method, depending on the type of plant and the chemical used. The effective use

of herbicides to control terrestrial weeds has encouraged their use in aquatic situations, however less is known about the effects of herbicides in the latter situation.

Advantages of herbiciding are that large areas can be treated quickly, cheaply and in shallow water, and success is often very good. Disadvantages are related to their non-specific toxicity and ecological side-effects, and hazards associated with contamination of surrounding land and water supplies. Prolonged aquatic weed control requires repeated application.

Knowledge of the plant's growth cycle is important so that herbicide application can be timed so as to be most effective. Other factors which may affect the success of the application are temperature, lake levels and water chemistry. Herbicides are most effective in the long term when water level and temperature are stable (Allan 1971).

Experiments in herbicidal control of Elodea have been conducted at Lake Wabamun, Allan (1971), in conjunction with the provincial and federal governments, initiated a three year program for 1971, 1972 and 1973 in Kapasiwin Bay. Herbiciding experiments were also conducted by Gallup et al. (1973). In 1974 no experiments were done because a storm removed much of the Elodea. In 1975 the Canada Department of Agriculture conducted tests that were monitored by Beak (1980).

Paraquat and diquat, the herbicides that have been used experimentally at Lake Wabamun, are organic water soluble compounds that are absorbed by aquatic vegetation. They are effective on a wide range of aquatic weeds and are non-toxic to fish at concentrations well above those used for weed control. They disappear quickly from the water by adsorption to sediments, suspended colloids and aquatic plants, and to

some degree through uptake by plants and algae. Herbicide levels are usually non-detectable within seven days (Beak 1980).

In initial tests at Lake Wabamun, low concentrations of a paraquat-diquat mixture (1 mg/L) were injected just below the surface. Fish moved out of the area and returned after the herbicide had been absorbed or broken down. An in-lake concentration of 0.5 mg/L was inadequate to kill Elodea (Reid, Crowther 1973).

Beak (1980) reported that the most effective application was a 1:1 paraquatdiquat mixture sprayed on the water surface or injected below the surface to a depth of up to 0.6 m to establish a concentration of 1.0 mg/L. This killed most species and little regrowth occurred during that growing season, but had little effect on phytoplankton or benthic invertebrates. They also noted:

1. Herbicide was less effective in deeper water;
2. Algal growth appeared near the dead plants;
3. Currents, waves and turbidity reduced the herbicide's effectiveness;
4. Herbicide mixtures tested were not selective; and
5. Herbicides were most effective on rapidly growing plants.

Gallup, Rasmussen and Hickman (1973) reported that herbicide application (a 0.5 ppm concentration of a paraquat-diquat mixture) caused a reduction in zooplankton density within 24 hours with species affected differentially. However, two weeks later, populations had increased to their original size. Laboratory applications of 0.5 ppm and 1.0 ppm herbicide solutions to several zooplankton species indicated that within 10 hours the animals became paralyzed and died. Gallup et al. (data) suggested that significant reduction of chironomids by herbiciding over a large area could have detrimental effects upon available food for whitefish. The herbicide tests had little effect on benthic algae or water quality.

Gallup et al. (1973) recommended that herbicide applications should be confined to Elodea beds only so as to keep the area as small as possible. They cautioned against blanket applications and recommended further studies.

3. BOTTOM BARRIERS

Bottom barriers inhibit weed growth by totally shading and/or altering the substrate. Some successful techniques include blanketing the bottom with sand or black polythene film but they are costly to install and maintain, and are impractical for large areas (Beak 1980).

One promising technique is the application of a closely woven fiberglass screen (Mayer 1978) over the lake bottom when plants are established in early summer. This material physically prevents growth into the upper water and may eventually kill the plants. This is most suitable for small areas in front of cottages, beaches or marinas. The material costs about $\$1.50/m^2$ U.S.; a 130 m^2 area of coverage would cost about $500. U.S. including installation (labour and materials) (M. Perkins, pers. comm.)

4. DREDGING

Dredging to depths below the photic zone limits light for rooted plant growth and also removes nutrient-rich sediments. In Lake Wabamun, the photic zone is approximately 5.0 m therefore dredging the whole lake to this depth would be very expensive and totally impractiable. As well disposal of the dredge spoils would present a major problem (Reynoldson 1981).

Experimental shallow dreding was done in Moonlight Bay by Alberta Environment (Reynoldson 1977). A floating Mud Cat dredge removed 45 cm of sediments from a 0.78 ha area in 21 days at a cost of $23,200. Operation of the dredge accounted for 81% of the costs. The dredge sludge was pumped to settling ponds before returning to the lake. Total solids and nutrients were slightly higher in the returning water. The cost per acre of dredging versus weed harvesting and herbiciding is shown in the following table.

Table 22. Cost comparison of three aquatic weed control methods. (adapted from Reynoldson 1977).

Treatment	Area Treated	Total Cost	Cost/Acre
Harvesting	138 acres	$56,000.00	$405.79 (1975)
Herbiciding	11.1 acres	$ 6,700.00	$603.60 (1975)*
Dredging	1.92 acres	$23,233.50	$12,100.78 (1977)

*Cost includes use of a curtain for experimental control. In actual field situation curtain probably would not be used; cost would then be $243.24/ac.

Within a year Elodea had colonized the dredged area, which was occupied by Myriophyllum and Potamogeton prior to dredging (Beak 1980).

5) DILUTION AND FLUSHING

Theoretically plant growth could be reduced by dilution with inflow water having a low nutrient concentration. For Lake Wabamun the only practical source would be the North Saskatchewan River. Average total phosphorus in the river is higher than in the lake although bio-available phosphorus is slightly lower in river water.

Another possible technique is flushing by high volumes of water. The hydraulic residence time (presently 8.9 years in Lake Wabamun) would have to be reduced to weeks. A diversion flow of 12 000 L/sec (425 cfs) would produce a residence time of one year (Mitchell 1981). Again, the only possible source would be the North Saskatchewan River. The only other nearby river, the Pembina River, lacks the volume to divert this much water.

Potential problems are nutrient and sediment loading from the inflowing water. River diversion with continuous flow could result in increased eutrophication, however some long term benefit to the lake might be achieved by diversion only when sediment and nutrient levels in the river are low (Mitchell 1981).

To pump the volumes of water required for flushing (i.e., 12 000 to 14 000 L/sec) a pipeline of at least 2.13 m diameter would be required with several turbine-type pumps of 6 000 HP each. Pipeline, pumps and construction costs would be at least $100 million (H.Cameron, pers. comm.) width outlet channel construction and land aquisition are additional costs.

6) GRAZING

This is a type of biological control through the introduction of herbivorous animals such as carp, cichlids, manatees and various molluscs. It is extremely risky as the effects of the introduced species and/or their diseases and parasites on native biota are unpredictable and may be irreversible. The Alberta government prohibits the introduction of non-indigenous species into the province (Beak 1980).

Ferguson, Harrison and Associates (1974) recommended to the ERCB introduction of the white amur fish (Catastomus idellus) to Lake Wabamun to control weeds and enhance the lake's recreational, tourist and fishing potential.

7) PATHOGENS

Experiments using species-specific pathogens have been attempted (referenced by Beak 1980). Hazards include the spread of the pathogen to desirable species and the development of disease-resistant strains of weeds. The provincial government prohibits the import of pathogens.

8) COMPETITION

Competition from other aquatic organisms to control weeds has been investigated, such as fertilizer-stimulated phytoplankton blooms to reduce light and smothering of macrophytes with benthic algae. However these methods are not acceptable for a recreational lake, as the treatment is more objectionable than the problem (Beak 1980).

9) SHADING

Shading with black plastic sheeting can be effective, but is impractical over large areas, and during the treatment the area under

the shades cannot be used for recreation. Techniques using non-toxic dyes that limit light penetration are still in experimental stages (Beak 1980).

10) WATER LEVEL MANIPULATION

The lowering of lake levels, or drawdown, which expose macrophytes and kills plants by desication and/or freezing would be unfeasible in Lake Wabamun due to the difficulty in draining the lake, lack of flow to replace the water and the gentle slope and shallowness of the basin. Removal of over half the water volume would be necessary to expose all of the littoral zone. Biological and recreational impacts would be tremendous (Beak 1980).

Plant growth is reduced by extremes of water level. Stabilization of water level would tend to promote plant growth in shallow areas now somewhat controlled by fluctuations (Beak 1980).

11) NUTRIENT LIMITATION

The inactivation, dilution or removal of nutrients in the substrate or water column would inhibit macrophyte growth. Methods include: (1) precipitation of nutrients using alum, fly-ash or clay; (2) dilution of lake water with nutrient-poor water; (3) aeration of water to retard sediment nutrient release; and (4) removal of plants. The effectiveness and feasibility of these methods is questionable since rooted aquatic weeds obtain nutrients from the sediments and Lake Wabamun's sediment nutrient reserve is very large. Precipitation of nutrients is inadvisable since long term effects and recycling are not known (Beak 1980).

B. OPTIONS FOR CONTROL OF CAUSE

1) REDUCTION OR ELIMINATION OF THERMAL INPUT

The ERCB in 1975 required TransAlta to investigate environmental impacts of the thermal discharge as well as alternative cooling facilities, their estimated costs, effectivness and environmental impacts. Alternate cooling facilities studied by Montreal Engineering Company (1979) are summarized in Table 23. These included closed and open systems using spray nodules or cooling towers, deeper water discharge and tempering of discharge water with cool lake water. International Environmental Consultants (1979) described the physical, biological and socio-economic impacts of the alternatives. Negative impacts include fog generation, soil and sediment disturbance and siltation.

In 1981 the ERCB, having reviewed all pertinent studies and heard witness' testimony, ruled that alternative cooling facilities were unwarranted, that TransAlta could continue the thermal discharge but must expand the weed harvest program.

2. NUTRENT LOAD REDUCTION

Aquatic plants, both macrophytes and algae, grow in proportion to their nutrient requirements. If nutrient input is increased, plant growth increases. The nutrient in lowest supply relative to plants' growth requirements will limit or control the plant population. In most lakes, including Wabamun, this is phosphorus, since it occurs naturally in very low quantites (Mitchell 1981).

A quantitative nutrient budget for Lake Wabamun is a goal of the Alberta Environment eutrophication study, which will also attempt to

Table 23. Various feasible cooling alternatives for Wabamun Power Plant, as reported by Montreal Engineering (1979).

Type of System	Description	Estimated Cost (1979)
1. Closed System	- independent of lake	
a) with cooling towers	- two towers each 20 m high 23 m wide and 132 m long - water flows down through grid in contact with air drawn upward by induced draft fans	
(i)	Lake Wabamun used for make-up and blow-down	$20,391,000.00
(ii)	North Saskatchewan River used for make-up and blow-down	$35,778,000.00
b) with sprays	- cooling water pumped through spray nodules 5.2 m into air, collected in canal - canal size required: 2987 m long, 43 m wide - intake and discharge canals would be connected	
(i)	Lake Wabamun used for make-up and blow-down	$18,211,000.00
(ii)	North Saskatchewan River used for make-up and blow-up	$33,598,000.00
2. Open System		
a) with helper cooling towers	- two towers, each 20 m high 23 m wide, 110 m long - discharge water within 2.8°C of June ambient lake temperature	$18,325,000.00
b) with sprays	- spray nodules in enlarged discharge canal - canal extended 700 m into lake, widened to 67 m	$10,158,000.00
3. Once through cooling with discharge to deeper part of lake	- pipeline pumps cooling water to discharge point 732 m into lake, 4.6 m below surface	$ 5,110,000.00 to $ 6,803,000.00
4. Tempering of discharge water by mixing with cool water	- cool water from intake canal pumped into discharge canal, to mix with warm water - discharge water within 2.8°C of ambient - greater volume of water handled than at present	$ 6,381,000.00

determine the feasibility of nutrient control. The final report is expected in 1983. Preliminary findings suggest that uncontrollable nutrient sources (i.e., precipitation and bottom sediments) are significant contributors of phosphorus. Streams and flyash lagoon effluent are also important contributors; control of some phosphorus input from these sources may be possible. Sewage is another controllable input, but probably amounts to at most 6% of the total phosphorus input to Lake Wabamun (P. Mitchell, pers. comm.)

Given the naturally productive nature of Alberta lakes, a drastic improvement in water quality is not a reasonable expection even if some degree of nutrient control is feasible (P. Mitchell, pers. comm.).

C. SUMMARY OF OPTIONS

In summary, options for control of aquatic macrophytes that are worthy of serious consideration are:

1. Weed harvesting;
2. Herbiciding;
3. Nutrient input reduction; and
4. Limited application of bottom barriers.

Options which appear entirely uneconomical, unfeasible or biologically unsound include:

1. Alternative cooling systems;
2. Introduction of grazers (fish);
3. Introduction of pathogens;
4. Competition;
5. Shading;
6. Large scale dredging; and
7. Flushing.

In the last ten years alternate cooling systems or discharge manipulation received much consideration; however, the accumulated information indicates that they would not alleviate the weed problem throughout the lake, would be uneconomical, and some schemes might aggravate the problem.

Herbiciding is potentially a very effective and inexpensive weed control method. However, the large-scale and long-term biological effects, including bioaccumulation and mutagenic effects, are unknown.

Weed harvesting is an effective, predictable and relatively cheap control method without serious ecological impacts provided certain guidelines are followed. However, it must be repeated annually.

The trophic status of the lake is a response to the nutrient load to the lake from both external and internal sources. Although many nutrient sources are uncontrolable, stream and diffuse runoff and sewage seepage are sources which offer some possibility of control by improving land use practices. Therefore to maintain present water quality and to prevent an increase in the eutrophication rate it is important that nutrient loading is not increased by human activities.

IX SUMMARY

A. INTRODUCTION

1. The purpose of this report is to review all scientific literature pertaining to Lake Wabamun.

2. Lake Wabamun is an important recreational and industrial resource; developments include numerous summer cottages and subdivisions, five summer villages, a provincial park and two coal-fired power plants operated by TransAlta Utilities Ltd.

3. The lake is a typical shallow productive prairie lake supporting dense summer growths of aquatic macrophytes which are a nuisance to recreationists.

4. In 1973 the Energy Resources Conservation Board (ERCB) required TransAlta to determine if the power plant thermal effluent contributed to weed growth in the lake, and to investigate alternate cooling facilities.

B. BACKGROUND

1. Paleolimnological evidence indicates that Lake Wabamun has always been productive since glacial retreat about 10,000 years ago.

2. Bedrock north, south and west of the lake is the Paskapoo Formation, which contains mineable coal; east of the lake it is the Edmonton Group which underlies the Paskapoo.

3. Topography has been modified by continental glaciation; the lake was probably formed by glacial ice-thrusting. Surficial deposits are of glacial origin.

4. Soils are mainly of the Gray Wooded type and have limitations for agriculture.

5. The lake level fluctuates considerably; enhanced evaporation due to power plant operation has not caused a decline in lake level as was once feared.

C. HUMAN USE

1. Lake Wabamun has been used for recreation since the early 1900's.

2. Wabamun village is the main permanent population centre. There are five summer villages and numerous cottage subdivisions around the lake as well as several camps and yacht clubs.

3. Wabamun village has a secondary treatment sewage lagoon with discharge to the Lac Ste Anne watershed. Other residences use individual septic systems or pit privies.

4. Wabamun Lake Provincial Park is the only major public recreation facility.

5. Sport fishing has become a more important activity than commercial fishing; winter ice-fishing is more popular than summer fishing.

D. POWER GENERATION

1. The Wabamun thermal plant on the north shore, commissioned in 1956 and with a present capacity of 569 MW, uses lake water in a once-through cooling system, discharging heated effluent water at 10° to 15°C above ambient lake temperatures into shallow Kapasiwin Bay.

2. The Sundance plant on the south shore, commissioned in 1970 and with a present capacity of 2100 MW, has used a cooling pond independant of the lake since late 1975.

3. The thermal effluent water keeps an ice-free area in the winter.

E. PHYSICAL AND CHEMICAL CHARACTERISTICS

1. The normal temperature regime of the lake is winter ice cover and inverse stratification; complete wind mixing and fairly isothermal conditions prevail in spring, summer and fall; permanent summer stratification does not occur. Temperatures range from 0°C to over 20°.

2. The thermal discharge plume forms a thin surface layer over the ambient water; temperature patterns in the plume area vary with wind.

3. Dissolved oxygen is ample throughout the year and oxygen is usually present to the bottom. Surface water is usually oxygen saturated; in the plume it is supersaturated.

4. Wind mixing and internal currents keep water quality quite consistent throughout the lake.

5. Bottom sediments are very thick; the upper sediments are loose and unconsolidated. Sediments contain significant amounts of biologically available phosphorus.

6. Lake Wabamun water quality compares favorably with other Alberta lakes. Its trophic status is mesotrophic to moderately eutrophic.

7. The lake is under an evaporative regime. Surface inflow and outflow are relatively minor. Groundwater recharge, mainly from the coal units north of the lake, is probably important. The direction of groundwater flow is from northwest to southeast.

8. Although a quantitative nutrient budget has not yet been determined, phosphorus appears to be the limiting nutrient. Major sources of phosphous input are surface runoff, ash lagoon effluent, precipitation and sediment recycling. Sewage makes only a minor contribution; groundwater is unknown.

F. LAKE BIOTA

1. The phytoplankton species composition and abundance are characteristic of a meso-eutrophic state; blue-green algal blooms rarely occur.

2. The thermal effluent indirectly causes increased algal production by maintaining an ice free area where light can penetrate, thus extending the growing season through the winter. Summer phytoplankton production is reduced in the discharge area due to shading from dense macrophytes.

3. Phytoplankton species composition is not altered by the thermal effluent.

4. Epipelic (free-living benthic) algal standing crop is increased in the discharge area due to increased winter light.

5. The plant outlet canal supports a large crop of filamentous and blue-green algae.

6. Benthic diatoms are little affected by the thermal effluent except within the outlet canal where species diversity is reduced.

7. Epiphytic algae (algal attached to submerged surfaces) show increased standing crop and reduced species diversity in the discharge area. The growing season for both algae and its substrate (emergent macrophytes) is extended.

8. Rotifers, which dominate the zooplankton community in spring and early summer, exhibit accelerated egg production in the effluent area. Eggs are less tolerant of elevated temperature than adults.

9. Species composition, but not biomass, of crustaceans, which dominate the zooplankton after mid-July, is altered in the effluent area.

10. Species composition of the benthic fauna is characteristic of a greater degree of eutrophication in the discharge area than elsewhere in the lake. This is mainly an indirect effect due to enhanced trophic status of the sediments because of abundant decomposing macrophytes.

11. Thermal enrichment causes accelerated egg development and growth in the snail Physa gyrina, permitting year round reproduction. Snail parasite transmission is also enhanced.

12. Whitefish and pike populations have fluctuated over the years and have at times suffered from overfishing.

13. Thermal effluent may be detrimental to whitefish spawning; the Sundance plume (now eliminated) threatened an important spawning area.

14. Fish kills, although rare, have been documented, due to "cold shock" and deoxygenation in Goosequill Bay.

G. AQUATIC MACROPHYTES

1. Aquatic macrophytes, abundant in shallow areas especially at the east end of the lake, are a nuisance to lake users.

2. Since 1968 a species change from Myriophyllum - Chara to Elodea has been documented. Elodea became a major nuisance in the early to mid-1970's.

3. A cause-effect relationship between thermal discharge and excessive weed growth has been investigated.

4. Sediment type and exposure to wind and waves are important determinants of plant species distribution. Local instability and high turnover rates are normal conditions of the aquatic macrophyte communties.

5. Elodea, rare in Alberta and not documented in Lake Wabamun prior to 1968, dramatically increased as an indirect result of the thermal

discharge. Elodea, which does not become dormant in winter, was able to continue growth throughout the winter in the ice-free area, outcompeting native species which become dormant despite the greater light availability in the discharge area.

6. Within only a few years most Elodea populations declined substantially; only the one at the Wabamun plant outlet remains vigorous. One disputed theory to explain the decline is sediment iron depletion by the plant.

H. CONTROL OF AQUATIC MACROPHYTES

1. Methods that might control symptoms of the macrophyte nuisance include weed harvesting, herbiciding, bottom barriers, dredging, dilution and flushing, grazing, pathogens, competition, shading, water level manipulation and nutrient limitation.

2. Of these weed harvesting and herbiciding offer the best results with reasonable cost.

3. Weed harvesting has been done by TransAlta since 1972; it is quite effective but must be repeated annually.

4. Weed harvesting may be detrimental to some invertebrates and small fish. Certain guidelines help to alleviate harmful effects.

5. Although herbiciding can be effective, effects of large scale application are unknown.

6. The thermal effluent has a localized effect on macrophyte growth and indirectly caused a species shift to Elodea; it does not affect the whole lake.

7. Alternate cooling schemes for the Wabamun plant have been studied; most would be very expensive, probably would not alleviate the problem and some would have major negative impacts. Elimination of the Sundance dishcarge did not reduce the weed problem in that area.

8. In 1981 the ERCB ruled that alternate cooling facilities for the Wabamun plant were unwarranted and required TransAlta to expand the weed harvesting program.

9. An abundant nutrient supply is more likely the cause of abundant macrophyte growth. Uncontrollable nutrient contributors are precipitation and bottom sediments. Nutrient sources where some control may be feasible are streams, fly ash lagoon effluent and sewage. Nutrient budget and nutrient control feasibility are now being studied.

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